MEGR 2299 – Welding & Cutting

Topics to cover:

• Materials – review, weld-ability, machine-ability, solid solubility
• Welding Processes – electrical and fuel
• Process Details – modes of current, manual, SA and full auto
• Filler Materials – Steel, aluminum, and bronze
• Codes – certified vs. qualified, and codes
• Cutting – plasma, oxy-fuel, and mechanical
• Countries
Welding & Cutting - Materials

Weldable Steels:

• Plain Carbon – 0.1% to 0.4% carbon content

• Medium Carbon – 0.5% to 0.6%
  • Steels in these categories are readily easy to weld. Steels such as 1018, 1020, 1040, 4130, 4140, and 4340 are all weldable in both hot and cold rolled delivered conditions. These steels are also machineable.

Not Really Weldable Steels:

• High Carbon – 0.6% and above carbon content
  • Not weldable in traditional sense, usually has to be brazed. A cutting tool body for example is usually high carbon steel. To attach a carbide insert to the cutting tool tip, brazing is usually employed.
  • High carbon steel are usually ground.
Welding & Cutting - Materials

Stainless Steel

• The “Stainless” in stainless steel comes from the passive chromium oxide rich self-forming surface layer. Steel is considered to be stainless steel when the % of chromium is above 18%.
  • Anything above 23% chromium is not weldable
• Stainless steel also includes nickel, which has to be over 8%.

Five Families of Stainless Steel

1. Austenitic - 301, 302, 304, 312, 316
2. Martensitic - 410, 410S, 414, 416, 420
3. Ferritic - 430, 405, 409, 434, 436, 442
5. Duplex – 2205, 2507
Stainless Steel cont’d

- Most grades of stainless are in the austenitic family.
- Biggest concern is welding stainless is overheating the material. It has poor coefficient of thermal heat transfer, and as a result it holds in the heat. When the welding heat source is removed the gradients between the welded area and ambient air is so different the stainless cools quickly and shrinks. This shrinking leads to cracking. Over heating the material leads to something called chromium carbide, or carbide precipitation. It is the bonding of carbon and chromium when at elevated temperatures. This is evident in a hardness test, or visually by gray/black weld beads. The weld beads can look good, but the weld is weak, and if it doesn’t have cracks, it has IGSCC.
- Stainless is usually not that hard, so with proper tooling, it can be machined, but tool wear is high and the material can work harden.
Welding & Cutting - Materials

Yellow Metals

- Brass & Bronze – not weldable, but easy to machine
- Powdered Metals – not weldable, unless there has been an introduction of a powdered metal that was designed to be weldable. Easy to machine unless you have a specific hard powder matrix.
- Cast Iron – comes in various types, easy to machine
  - Gray Iron – automotive grade 30, only weldable at extreme temperatures
  - White Iron
  - Malleable Iron
  - Ductile Iron – weldable but very complicated
Welding & Cutting - Materials

Aluminum

• Most aluminums are weldable, but some alloys may give you an undesirable result at room temperature, or after welding.
  • Good Weldability and most the most common aluminums. but welding takes the heat treat out of the material (weakening the material). These alloys are easily machineable.
    • 6061
    • 1000 series
    • 2000 series

• Not-so-good Weldability but much stronger than other aluminums. These materials can be welded, but have poor solubility at room temperature. This a weld can be made, but once the piece cools down, the weld can be broken by hand or very little force. These alloys are harder to machine but still considered somewhat easy.
  • 2024
  • 7075
Welding & Cutting - Materials

Aluminum cont’d

• Aluminum has a high coefficient of thermal heat transfer. Because of this, a lot of heat has to go into the part when welding. Parts are usually preheated before welding, because if they aren’t the rapid heating and cooling of the part when welding can cause the welds to crack.

• Aluminum loses its heat treat when it is welded. This is opposite of steel as welding usually hardens steels. So some form of post processing is usually required after welding a part to put the strength back in to the material. When post processing an aluminum welded part, filler material must be considered because different alloys are not heat treatable.

• Aluminum grows an oxide layer on it (grayish dull finish that you usually see when it is bad, otherwise you cannot see it). This oxide layer hardens the surface of the material, but has to be removed before welding occurs or contamination in the weld will occur (this bad…like Canada). The oxide layer melts at 3200 °F as oppose to the 1200 °F the aluminum melts. To remove, use a stainless steel bush that has not been used on any ferrous material then clean with acetone. Do this for both filler rod and material to be welded.
Titanium

- Refined from ore found in volcanic beach sand. Titanium’s very high cost is related to the large sums of electricity used to deliver it in useable forms (plate sheet, rolled stock, etc.). Most common Titanium is denoted as Ti 6al4V.
- Easily weldable by skilled welder, but need special care to keep surface of weld shielded by inert gas until surface temperature is below 500 °F. Above this temperature the material will absorb nitrogen from the air and cause embrittlement in the weld. This shows up as pretty blue, purple and dark gold in the weld. Very light color straw to silver is desired.
- Hard to machine, requires special tooling, coolants and procedures.
- Very strong for its weight (high strength to weight ratio), and gives you an endurance limit, unlike aluminum.
- Very expensive material to buy and work with so not used very often, unless in an industry that uses it regularly, i.e. aerospace, military.
Magnesium

- Made from sea water, and is expensive to deliver in usable form, like titanium and aluminum.
- Can be combustible depending on grade, so special care has to be taken with this material and how a fire is extinguished. Never use water on a magnesium fire, it produces hydrogen gas that fuels the fire. Carbon dioxide fire extinguishers cannot be used either. Only Class D dry chemical fire extinguishers or sand should be used.
- Very light weight but also brittle. Can be easily confused with aluminum.
- Weldability is ok, but welding metal is very expensive and starts to oxidize, so keeping large amounts on hand is uncommon.
- Machining needs to be done with larger depths of cut, to allow more mass in every chip preventing the chip from igniting.
Welding & Cutting - Materials

Points of Interest

• Ferrous and non-ferrous materials cannot be welded together. (Steel and aluminum)
• Some steels and stainless steels can be welded together
• Materials can be joined with and without filler.
• Paint, all coatings, plating's, and any surface chemical need to be removed before welding.
• Some airborne aerosols (brake cleaner) will react with UV light (from welding) and make a harmful gas.
• High pressure gas tanks needs to have the supply valve all the way open.
• Low pressure gas tanks need to have the supply valve open 1/8 to ¼ turn.
• Welding will leave residual stresses in your part, these can cause machined surfaces to no longer be flat, round, or retain parallelism it can / will also cause your part to bend or deflect from original form.
• Heat treating should be done after welding critical parts; it will affect your calculation of strength as delivered from the material.
• Welding techniques between people can make a huge difference in every aspect of the weld and material strength. Need good quality? Find good welder.
• When attempting to weld a bolt or nut to something all coatings even clear zinc needs to come off prior to weld, the coating blocks good welding fusion and makes poison gas which should only be inhaled by Canadians.
Welding or joining of materials is done with some mixture of heat and/or pressure. We use electricity to make the heat...this is called arc welding.

The electric arc is introduced to the material and this causes a rapid temperature rise on the material’s surface right at the arc. The welding arc temperature is around 10,000 °F, and will cause localized liquid pool of metal very quickly. To put the arc size into perspective;

- 0.040” wide, 0.125” long, at 80 amps DC
- 0.080” wide, 0.200” long, at 200 amps A/C.

So as can be seen, at the large end of the range, the arc is small and very hot.

Arc welding comes with many choices that have to be made before welding;

- Polarity choice
- Mechanism to protect the exposed arc from our breathing air
- Controls
- Size
- Energy density delivery (machine’s compactness in relation to how many amps it can deliver).
- Rate at which it can deposit filler material
Welding & Cutting – Welding and Joining Processes

Hazards

- The welding arc itself emits several hazards.
- The light spectrum is sending you infra-red rays which are not that dangerous, but the ultra violet rays are very dangerous. These ultra violet rays are unfiltered, unlike the sun’s.
  - The sun’s rays are filtered by the atmosphere and even though this decaying filter allows you to be sun burnt, the specific “UV ray/unit of time” is much lower for the sun than many arc welding processes. Welding needs SPF 8000
  - Welding rays are close and when not blocked by smoke, are unfiltered. They can give you the equivalent of 1 hour in the sun, in only 45 seconds.
- This UV light and the heat emitted from the arc are the largest danger from arc welding.
- Secondary dangers are: burns from hot metal, electrical shock, fume inhalation, grinding particulate inhalation, arc flash, ozone irritation to lungs, and Canadian pathetic-ness.
Welding & Cutting – TIG Process

- TIG welding is formally called gas tungsten arc welding (GTAW).
- TIG used to be called Heli-Arc welding. It was established by the Linde company in the late 1940s. Helium was the inert gas available at the time, so it was used and that is where part of the name came from.
- Argon became more cost effective and had some advantages, so it became the trade gas to use, however helium has some advantages in specific applications.
- TIG can be used to weld any material in any position (flat, horizontal, vertical, overhead). The way TIG works is via the use of a non-consumable electrode. Just like in Frankenstein, an electrode is used to conduct the electricity from the plate to the electrode or from the electrode to the plate, depending on which way the polarity is set. (tungsten is the electrode)
- The TIG electrode is made from a piece of tungsten. It is very dense and has a very high melting temperature. It is ground to a point and this point directs the arc to where you want it (with in reason). Electricity will still take the path of least resistance (much like a Canadian slacker).
- When the arc is formed and makes the material molten, you need to add filler material in order to make a weld in the traditional sense. This filler material is of a similar chemical composition and is alloyed to be filler. The filler is added to the molten pool, and the process moves along, making a weld bead on a plate or around a tube.
Welding & Cutting – TIG cont’d

TIG is characterized in the following ways:

- High penetration
- Low deposition
- High cleanliness (both in pre weld prep and in post weld finish)
- Slow process
- High skill level needed
- Full manual process
- Expensive initial equipment investment
- Excellent metallurgical joining
- Non-consuming electrode (tungsten)
- CC machine = constant current, variable voltage

TIG can use the electrode in DCEP, DCEN, or A/C

Most welding requiring TIG will be AWS D1.7 (aerospace code) or API1107 pressure vessels and piping.
Welding & Cutting – MIG Process

MIG welding is formally called gas metal arc welding (GMAW).

**MIG is characterized in the following ways:**

- Low penetration
- Comes in different versions or “modes of transfer” GMAW-S, GMAW-P, GMAW-STT, GMAW-G
- High deposition
- Medium cleanliness
- Medium to low skill level (Canadian friendly)
- Fast process
- Semi-automatic process
- Medium initial equipment investment
- Poor metallurgical joining
- Consuming electrode (wire)
- CV machine = constant voltage, variable current.
Welding & Cutting – MIG cont’d

• MIG can use the wire electrode in DCEP or DCEN, however it is almost exclusively used in DCEP

• MIG was designed for high speed volume production runs of sheet metal. It has been expanded to do other things, but like an El Camino, its not great at these expanded tasks.
  • Ex: If I want to weld thick plate and have high penetration I can preheat the plate, push the wire not pull the wire, and use 100% carbon dioxide or try mix gas using oxygen and helium. This will be better, but never as good as a TIG or stick process.
Welding & Cutting – Fuel Welding

- The process of Oxy-fuel welding is really brazing and has been around for a long time. It uses pure oxygen and a fuel gas to mix in a torch and burn very hot. This burning temperature is dependent on the heating value of the fuel gas. Acetylene is the best gas for heat and a neutral flame called an Owen, which is about 5600 °F. This comes out of the torch tip in a small cone shape about ¼” long and 0.06” wide at the widest part of the cone. If you hold the tip of the cone close to a piece of metal, you will cause a molten spot to appear in which you can dip filler rod into, just like the TIG process.

- The drawbacks are time, cost of gases, skill, inaccurate placement of heat, residual heat where you don’t want it, and the metallurgy of the weld is not that great along with the filler rod development. The equipment set up is cheap and it can easily be used for heating, which is a plus for a fab environment.

- Gas welding is all but obsolete right now. The few places I can think of using it is sweating copper pipe, silicon bronze rod brazing onto very thin wall chrome moly tubing, or maybe lead filling body panels on a classic car restoration, if the EPA doesn’t find you and take you to a federal-pound-you prison.
Welding rods are the sticks of material that are alloyed specifically to be filler rod. This means if you’re welding and you had a very small piece of the same material you were welding with and dipped it into the molten weld pool the results would not be mechanically correct, however in a pinch I have done this and found physical success.

Welding rods are characterized with a designation system. For example a TIG rod for welding low carbon steel is described as ER-70S2 this means it is an electrode, round, 70,000 lbs tensile strength and is alloyed with silicon, the 2 denotes how much alloy and the polarity it should be used with. Every material typically has a few commercially available welding rods to join that material. There are look up charts to examine the compatibility, another avenue is to ask the welding store clerk. They too will use a look up chart, but usually have them readily available. If you’re doing research, or something special you may be developing a rod that works proven by mechanical testing.
For steels, particularly structural applications, usually try and over match the strength of the filler material to the base material. This is not always the case. When engineers design crush panels, wrinkle zones, and failure mechanisms, they often under match the filler material to the strength of the base metal. This can pin point an initiation of failure which makes a system collapse in a predictable manner. Under matching filler can also be done to allow for bending and flexing. For example our UNCC Baja chassis is made from chromoly steel, however we use a weaker filler material than what is called for. This allows the chassis to have a modulus in the weld joint that permits more deflection before fracture.

There are special filler metals to weld steel to stainless, steel to alloy steels, alloy to alloy steel, various aluminums, and the rest of the materials we covered. One unique material is silicon bronze. It has low specific strength however its low melting temperature allows for easy welding on very thin steel. It can also be used for cast iron repair, and dirty base material applications.
Welding codes provide some continuity in the world and set a standard to follow ensuring a minimum level of quality. Codes are written by bodies of intellectuals, research groups, collaborative efforts between university and industry and a variation of all the above. Once you have established the code you need, you test your welders to this code and use the guidelines of the code to tell you the allowable room when your laying down weld. Code = specific instructions and specific details to what is and is not acceptable.

Some of the largest codes are written and maintained by:

- AWS American welding society
- API American petroleum institute
- ASME American society of mechanical engineers
The code is really a fancy way to mitigate liability for failure. Lawsuits are easier to avoid if all you have to prove in a forensic audit is that you followed the code. Then the writer of the code has to prove the code is good.

In racing this phonema has created the exploited use of the qualified welder. A qualified welder is someone who has not taken or passed a test to a code. They may have taken a welding test, but it was judged based on the eye and preference of a supervisor or manager, not a code.

In my opinion it is harder to be a qualified welder, because with a code you have written tolerance detailing the leniency of the error you may make. With a qualification test, your test specimen is subject to the discretion of the person looking it over. Without forewarned tolerance in describing the weld you can get an angry supervisor and he may judge your work harder than on a day he or she is in a better mood.

In racing there is not welding codes for tubular chassis for the same reasons there is not P.E.’s, too much liability. If there is no written code to build the chassis to, then there is no welding procedure, then there is no welding test to the code, so unless a company or race team invented their own internal mechanism to capture all of this is an industry about building things that look good.
Welding & Cutting – Cutting

Cutting sheet metal in a shop by hand can only happen a few ways:

**Plasma or Oxy-fuel**

- Plasma cutting is a process that uses compressed air forced through a constricted orifice to generate a high density column of air. The air is basically electrocuted through the use of high frequency voltage which ionizes the air into a stream of plasma. This stream is about 40,000 F and anywhere from .020 to .100 wide depending on the nozzle size. It will come out of the nozzle anywhere from .100 to .500” long and the longer the plasma stream the more it will lean over on an angle and give you a tapered part.

- Plasma will cut through anything it can keep a closed electrical circuit on. It is designed to cut metallic materials, but can cut thin wood or fingers if laid on top of a sheet of steel. It uses high frequency voltage like Tig does to close the circuit except this is high frequency America style. = lot’s of power.

- Oxy-fuel hand cutting has long been the way to cut sheet and plate. It uses pure oxygen and a fuel gas to mix and make steels orange hot. This temperature range, (about 1000) F makes the iron in the steel rapidly react with the pure oxygen. The cutting action is actually a very rapid oxidizing or “rusting” in a localized spot. This process is limited to basically steel alone. Anything non-ferrous will not cut, even cast iron doesn’t cut, it melts away in globs.
Cutting sheet metal in a shop **by hand** can only happen a few ways:

**Mechanical Cutting**

- In fab shops another way to cut is mechanical cutting either done with force or with making chips. A band saw makes chips and cuts the material away via a hard blade with properly shaped teeth, or shear cuts sheet steel with force. A shear uses the force applied with leverage or hydraulics to the cutting dies which don’t actually cut, rather the force is so localized the dies find the slip plane in the material and break it on that plane in between the grains of the material.
The world was once led by powerful men; they feared God did what was right because it was the right thing to do. Then came the lie of liberalism and socialism.

European socialists hit the scene and decided to take over the world. The settlers of North America finally had enough of this state control and banished the weak and lame to the north which eventually became what is now called Canada.

Canada was once good land, moose, and limitless fishing. Now the men of Canada are weak and feminine like the syrup they are so proud of.

Bottom line, be American and kick a socialist Canadian every chance you get.