WELD TECH NEWS is a newsletter for welders working primarily in maintenance and repair. Each issue contains useful information on materials (cast irons, steels, aluminum, copper alloys, etc.), welding products and welding techniques. By collecting each issue, the reader will soon have a handy reference manual covering all aspects of welding, brazing and soldering for maintenance and repair.

**ALUMINUM PROCESSES**

*Welding Issues and Processes*

Aluminum is being used in more and more metal applications. It is a lightweight metal, about a third of the weight of steel and has better corrosion resistance. It has excellent electrical conductivity and good strength to weight ratios. Welding with aluminum can raise different issues and problems than those related to welding steel. This issue of Weld Tech News is a follow up to Weld Tech News No.3, which speaks more to the specific aluminum alloys. This issue will deal with the various aspects of actually welding aluminum.

When welders weld aluminum they are typically transitioning from welding carbon steels. To begin to understand the issues of aluminum, it will be useful to make comparisons of carbon steel and aluminum. Aluminum is one of three classes of castings based on composition often referred to as “white metals”. The other two are magnesium and zinc. This article will only deal with aluminum.

**Aluminum and Steel**

Aluminum melts at 1,220°F (660°C) versus 2,750°F (1510°C) for steel. Its electrical and thermal conductivity is about four times greater than that of steel. So even though it has a lower melting temperature than steel, it can take more heat to weld because as fast as you are putting heat into aluminum it is flowing away.

Aluminum has a linear coefficient of thermal expansion about twice that of steel. Identical steel and aluminum pieces during welding will essentially expand the same due to the differences in their melting temperature ranges. Steel changes color during heating and becomes dark red just before its melting temperature. Aluminum does not change colors during heating so it is difficult to determine how close you are to the melting temperature when heating.
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Oxides

Aluminum does not “rust” because it does not contain iron. It will corrode but it has good corrosion resistance to water, air, oils and some chemicals. Oxidation is the chemical reaction between oxygen and other elements, which results in the formation of oxides. All metals form oxides and these can often be impediments to welding. All of the various welding processes deal with metal oxides in one way or another. Stainless is corrosion resistant because the chromium in stainless reacts with oxygen in the atmosphere to form an invisible chromium oxide film on the surface of the metal, which protects it.

Aluminum is highly reactive to oxygen in the atmosphere and instantly oxidizes when exposed to air. This is the white stuff you often see on aluminum surfaces, depending on how they are finished. This aluminum oxide film is 100-200 billionths of an inch thick, and if mechanically removed will immediately reform to 60 billionths of an inch thick. On many metals the heat of welding will remove the oxides. Remember that aluminum melts at 1,220°F (660°C) but the melting temperature of aluminum oxide is more than twice that at 2,750°F (1510°C). One of the problems of welding aluminum is that the heat of welding can melt the base metal long before the heat does anything to help with the removal of the aluminum oxide. Metal preparation will be covered later. Incidentally, aluminum oxide is rated right under diamonds in hardness, which is why it is difficult to join aluminum to other metals.

The aluminum oxide serves to protect aluminum from corrosion but will affect its appearance. Aluminum can be coated with a protective film through electrolytic action, which is referred to as anodizing and can give aluminum specific finishes. This anodized coating is actually clear, thick aluminum oxide that is many times thicker than the “naturally” occurring oxide film. This coating will absorb dyes because it is porous so that is why coatings are often colored. This is a factor in repair welding because the coating needs to be removed prior to welding. For fabrication of new aluminum that is to be anodized, the filler metal has to be correct for it to respond to anodizing the same way as the base metal.

Aluminum Alloys

Pure aluminum is alloyed with other elements to improve its characteristics. The principal alloys used for this are copper, magnesium, manganese, silicon and zinc. Other alloying elements are also used. These alloys by themselves or in combinations serve to strengthen the aluminum. The alloy content can also lower its melting temperature, increase fluidity (for casting), and most importantly, produce aluminum alloys that are heat treatable. Heat-treatable and non-heat-treatable are the two basic types of aluminum alloys. Copper, when alloyed with aluminum at 2% to 10%, increases its strength producing some of the highest strength heat-treatable alloys. Magnesium (0.3-5.0%) provides the highest strength non-heat-treatable alloys. Both are capable of being strain hardened. Manganese (0.05-1.8%) increases aluminum strength without reducing corrosion resistance or ductility. This alloy type is non-heat-treatable and retains its moderate strength at elevated temperatures. Silicon (0.6-21.5%) increases aluminum fluidity and lowers its melting temperature making it the main alloy for castings. Alone it produces a non-heat-treatable alloy but when combined with magnesium, it makes a heat- treatable aluminum alloy. The highest strength heat-treatable aluminum alloys are produced by adding zinc (0.8-12.0%) to aluminum, along with other alloys like copper. In order to weld aluminum, it is important to understand the various alloys and their effect on
the final metal, and the systems that identify them. Wrought aluminum alloys are identified by a four digit numbering system with eight classifications. These numbers are often followed by an additional letter and number, which indicate heat treating or hardening. The cast aluminums are identified by a three digit number followed by a decimal number. Refer to Weld Tech News #3 for more specific information.

Some general guidelines as to aluminum alloys are that sheet, plate or bar are probably a 5000 or 6000 series alloy, as are extrusions. Castings are aluminum-silicon alloy and some are weldable and some are not. In general, there are weldable aluminums and non-weldable aluminums. There are weldable aluminums that when heat-treated become non-weldable. There are heat-treated alloys that are weldable but welding changes the heat treatment! It is important, when ordering aluminum for a welding project, to be sure that it is a weldable type and to know how welding will affect the properties of the weld metal. When making aluminum weld repairs, an effort should be made to know what the base metal is and what effect welding will have on it. Unlike many steel-welding situations, problem welds with aluminum may not be readily apparent. Let’s use two common aluminum alloys to illustrate these types of situations.

6061 and 7075

Probably the most common aluminum used in the U.S. is the 6000 series. It is relatively strong. This is an aluminum, magnesium (1%) and silicon (0.6%) alloy and is readily available in many forms such as tubing, sheet, bar and round stock and especially extrusions. The 6000 series will not work harden very easily, which lends it very well for running through high speed extrusion presses that make it economical to manufacture the various shapes. It is heat-treatable and a common version is 6061-T6. The T-6 indicates a specific heat treatment, which includes an aging treatment at 325°F to 400°F. The welding process will change the heat treat in the heat-affected zone of the weld. What does this mean? You will lose about 40% of the tensile strength in the heat-affected zone when you weld it! This needs to be factored in when designing or repair welding. Is it strong enough for the intended loads?

One of the highest strength aluminum alloys is 7075, which looks good in a catalog, but does not mean it is a good candidate for welding applications. Heat-treatable 7075 is an aluminum, zinc (5.6%), magnesium
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(2.5%), copper (1.6%) and chromium (0.3) alloy used on such applications as aircraft structures requiring high strength to weight ratios. It is also used for dies in the injection molding industry. Structural welds of this alloy are highly susceptible to cracking in the weld and heat affected zone. These cracks can be micro cracks that are not visible but can fail in service! This basically is due to the chemistry in the weld and is referred to as hot cracking, as the weld cools and solidifies the crack forms. All cracking in aluminum alloys is hot cracking.

Aluminum and Magnesium

Aluminum and magnesium are both "white metals" and are often confused, especially in repair situations. Both metals have weldable forms but obviously must be correctly identified. An effective way to field test for aluminum versus magnesium is to use a liquid acid solder flux such as ROCKMOUNT Gemini Acid Solder Flux. Simply grind a small shiny spot on the metal in question and put a drop of the flux on the spot. If it turns black and foams right away, it is magnesium. If it does not react at all, it is aluminum. If it reacts slowly and just a little, then it is an aluminum alloy. Magnesium is electric welded with the GTAW and GMAW processes.

Welding Aluminum: Preparation

The two main elements of welding aluminum are cleaning and heating. As discussed, we have the aluminum oxide film to deal with, and the low melting temperature and high heat conductivity of the metal. Also remember, aluminum does not change color when heated. The aluminum oxide film is porous, can grow in thickness and can trap moisture or other contaminants. It can also become particles trapped in the weldment during welding and can prevent fusion between the filler metal and base metal. Plasma cutting is a common way to cut aluminum, but this cut edge can lead to cracking problems in welded joints in some alloys. It is usually necessary to remove aluminum oxide mechanically prior to welding and to prepare plasma cut edges. This is typically done by grinding with an appropriate abrasive and then just prior to welding, cleaning with a dedicated stainless brush. Stainless brushes should be clean and used only on aluminum. Clean joints prior to fit up or fixturing.

Cleaning also requires the removal of all hydrocarbons such as those found in lubricants used for machining or cutting, before wire brushing. Solvents, such as acetone and alcohol, evaporate quickly, but remember, the popular citrus cleaners can be water based and leave residual moisture. Porosity in aluminum welds is usually caused by hydrogen bubbles trapped in the weld puddle as it solidifies. Remember that aluminum is a soft metal; sand blasting can impregnate the metal with sand particles.

Welders should not think of preheating aluminum in the same terms as that of steels or other metals. Preheating aluminum can help avoid weld cracking but remember too much heat can easily degrade the mechanical properties of the metal. The primary effect of preheating is to remove surface moisture. As a general rule preheat temps should not exceed 250°F (121°C) and time at temperature should be kept to a minimum. Use a temperature indicator to avoid overheating. Remember to cool slowly to room temperature, preheat when welding a thick piece to a thin piece and tack welds. Will aid in preheating.
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Welding Aluminum: Processes

Aluminum can be joined by soldering, brazing, stick welding, wire feed (GMAW) and TIG (GTAW). The best results are obtained by the electric arc processes of GMAW and GTAW. Gas and stick welding can be used where weld quality and high strength are not required.

Generally speaking, GTAW of aluminum provides the most versatility and quality, but is relatively slow. The highly concentrated arc allows for the most control of heat input and weld beads are smooth and spatter free. As mentioned, the two main elements of aluminum welding are cleaning and heating, and the AC current used for GTAW aluminum deals with both. The electrode negative phase of the AC cycle puts more heat into the base metal, helping with the heat conductivity. The electrode positive phase ionizes the gas causing it to clean off the oxides by literally blasting it off. With appropriate power sources these cycles can be adjusted and a more sophisticated power source provides a square wave output. Beware that not all inverter type power sources have AC for aluminum GTAW welding. Power sources require low current for thin metal and high current for thicker sections. Remember that 90 amps would be enough to weld 1/4” steel but it would take 180 amps to weld 1/4” aluminum. An air-cooled torch will work for welding at 200 amps or less; when working above 200 amps a water-cooled torch should be used. Thoriated tungsten used for GTAW of steels will work, but the AC current used for aluminum puts more energy into the tungsten electrode, so pure or zirconiated tungsten is recommended. Argon is used for gas shielding up to 1/2” thick and provides the best cleaning action. Gas flow should be 15 to 20 CFH. Use an argon-helium mix for thicker base metal to provide a hotter arc and deeper penetration. In some cases, aluminum is welded using DC straight polarity, as with steel, but for it to work properly, the shielding gas must be 100% helium. With the GTAW process, the welder must wait for the shiny, clean weld puddle to form before adding filler metal. Refer to Weld Tech News No. 16 for more information on GTAW.

With the proper power sources, aluminum can be TIG welded from the proverbial beer can up to 1” in thickness. GMAW is practical from 0.12-inch minimum up to any thickness. It is important to remember that to avoid weld-cracking, weld beads for aluminum should not be thin and concave. Filler metal should always be used and beads should be heavier and convex. They should have a higher crown than commonly found with steel.

The GMAW process works most effectively for thicker, large scale aluminum welding but requires much different techniques and parameters than steel. Wire feed welding of aluminum is truly “MIG” welding (metal inert gas) because only inert gas can be used. For thin base metal use 100% argon, above 1/2” thickness start to consider using an argon/helium mix to increase penetration. Spray transfer is the metal transfer preferred for aluminum. This makes it inappropriate for metal thickness less than 14 gauge, and power sources in the 130 to 170 amperage range would only be suitable for thicknesses up to 3/16”.

The spray transfer mode involves greater heat with good penetration and faster travel speed. It provides a smooth transfer of metal across the arc, no spatter and good weld bead appearance. Everything is faster than with steel. The push technique is required to provide better gas coverage for the molten aluminum and to preheat and clean the base metal. Avoid the short circuit transfer.
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The key factors are the higher heats required and the softness of the aluminum wire. Pushing the relatively soft wire through a wire feeder makes spool guns or push-pull feed systems the preferred methods for large scale aluminum welding. Wire feed guns with conduits longer than 10 ft. can become problematic. The largest diameter wire suitable for the application should be considered, to avoid feed problems and burnback. Due to the low melting temperature of the wire, the high heats required and heat expansion of the wire, it is prone to melting at the contact tube.

The electrode extension or “stickout” is greater for aluminum wire. To help reduce the risk of burnback it is best to set wire feed speed or amperage at the high end of parameters and work down. Other factors to consider are Teflon liners, U-shaped drive rolls and aluminum specific contact tips. Too much tension on the drive roll adjustment can flatten the wire and cause jamming.

Soldering aluminum can be effective for joining thin pieces or sealing cracks. Tensile strengths are minimal but melting the base metal or affecting temper is less of an issue. Soldering is the only way to join aluminum to other metals such as copper or stainless. The appropriate flux is required for these situations. Remember that soldering is done at very low heats so too much heat can be a problem.

Brazing aluminum can be effective but also problematic. Brazing alloys melt at a lower temperature than the base metal. Aluminum brazing occurs just below the melting temperature of the base metal and aluminum does not change color when heated so melt through is a problem. An old welder's trick is to use a sooty, straight acetylene flame to blacken the weld area of the aluminum. Then adjust the flame to a carburizing flame for brazing with the filler metal. Heat the joint area with the flame and the black soot on the base metal will magically disappear just when it is time to feed the filler metal into the flame.

ALUMINUM WELDING ALLOYS

The following is a list and brief description of alloys for joining aluminum. For more information please refer to the ROCKMOUNT welding manual.

Neptune-SS (7,500 p.s.i.) is a special very low temperature solder 320°F (180°C) with excellent wetting characteristics, which can join all aluminum alloys and zinc die-castings. It also joins aluminum to other metals such as copper and stainless. It is used with Neptune Solder Flux. If heating with a torch, heat indirectly and when flux boils add the alloy.

Neptune-S (32,000 p.s.i.) is a self-fluxing low temp solder 670°F (354°C) for sealing cracks and buildup of worn areas where strength is not required. It can be applied with an oxy-fuel torch but flows below the melting temp of the base metal avoiding overheating.

Neptune-G (34,000 p.s.i.) brazing alloy melts at 1050°F (565°C), which is just below the melt temp of aluminum and provides joint strength just below that of the base metal. It can be used on cast or sheet aluminum. Use with Neptune Flux. Neptune-GCF is a unique flux core version requiring no additional flux.
Neptune-AAA and Neptune-A (35,000 p.s.i.) are aluminum stick electrodes that provide excellent arc characteristics. They can be used on most weldable aluminum cast, sheet and tubing. They can also be used with oxy-acetylene to braze.

Neptune-TIG (34,000 p.s.i.) is the most suitable filler for a wide range of aluminum alloys. It has minimum crack sensitivity, excellent color match, may be anodized and is excellent for aluminum castings. It is ideal for repair applications where exact base metal is not known.

Neptune-MIG (40,000 p.s.i.) is the most suitable wire feed alloy for a wide range of weldable aluminum alloys. Very ductile welds that may be anodized. Fluid beads that avoid porosity and color match the base metal.

Neptune-TIG/M (37,000 p.s.i.) is for GTAW welding of magnesium. Suitable for a variety of magnesium components including cast and sheet. Use with AC.

AFTER BRAZING OR SOLDERING, REMOVE ALL REMAINING FLUX WITH HOT WATER. REMOVE ALL STICK WELDING SLAG WITH WIRE BRUSH.

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