Welding of Aluminum

Not All aluminums are weldable
Most aluminum alloys are weldable, but there are a fair number of them that are not. An Example is 7075 aluminum. The reason 7075 is singled out in this example is that it is one of the highest strength aluminum alloys. When looking for an aluminum alloy to use, many will start by reviewing a table that lists all of the aluminum alloys and their strengths. Unfortunately, few of the higher strength aluminum alloys are weldable - especially those in the 7000 and 2000 series - and they should not be used.

The one exception to the rule of never using 7075 for welding is in the injection molding industry. This industry will repair dies by welding 7075 - but it should never be used for structural work.

Here are some simple guidelines to follow when choosing aluminum alloys:

Alloy Series	Main Alloying Elements
1000 series	Pure aluminum
2000 series	Aluminum and copper. (High strength aluminum used in the aerospace industry)
3000 series	Aluminum and manganese. (Low- to medium-strength alloys, examples of products using these alloys are beverage cans and refrigeration tubing)
4000 series	Aluminum and silicon. (Most alloys in this series are either welding or brazing filler materials)
5000 series	Aluminum and magnesium. (These alloys are used primarily for structural applications in sheet or plate metals - all 5000 series alloys are weldable)
6000 series	Aluminum, magnesium and silicon. (These alloys are heat treatable and commonly used for extrusions, sheet and plate - all are weldable, but can be crack sensitive. Never try to weld these alloys without using filler metal)
7000 series	Aluminum and zinc. (These are high strength aerospace alloys that may have other alloying elements added)

If a high strength aluminum is required, use the 5000 series high magnesium alloy instead of a 2000 or 7000 series. The 5000 series alloys are weldable and will produce the best results.

Strength of aluminum welds compared to parent material
In steels a weld can be made as strong as the parent material, but this is not the case with aluminum. In almost all instances, the weld will be weaker than the parent material.
To further understand why this occurs, let's look at the two classifications of aluminum alloys: heat treatable and non-heat treatable. The latter category is hardened only by cold working which causes physical changes in the metal. The more the alloy is cold worked the stronger it gets.

But, when you weld an alloy that has been cold worked, you locally anneal the material around the weld so that it goes back to its 0 tempered (or annealed) condition and it becomes "soft". Therefore, the only time in the non-heat treatable alloys that you can make a weld as strong as the parent material is if you start with a parent material that is a 0 tempered material.

With heat treatable aluminum alloys, the last heat treatment step heats the metal to approximately 400° F. But when welding, the material around the weld becomes much hotter than 400° F so the material tends to lose some of its mechanical properties. Therefore, if the operator doesn't perform post-weld heat treatments after welding, the area around the weld will become significantly weaker than the rest of the aluminum - by as much as 30 to 40 percent. If the operator does perform post weld heat treatments, the proprieties of a heat treatable aluminum alloy can be improved.

The following is a guide as to which series of aluminum alloys are heat treatable and which are not:

Heat treatable series:		2000,	6000,	7000.
Non-heat treatable:	1000,	3000,	4000,	5000.

Shielding gas used for aluminum welding

For both TIG (Gas Tungsten Arc Welding or GTAW) and MIG (Gas Metal Arc Welding or GMAW) use pure argon for aluminum materials up to ½" in thickness. Above ½" in thickness, operators may add anywhere between 25 to 75 percent helium to make the arc hotter and increase weld penetration. Argon is best because it provides more cleaning action for the arc than helium does and it is also less expensive than helium.

Never use any shielding gas that contains oxygen or carbon dioxide, as this will oxidize the aluminum.

Tungsten Electrode in TIG welding of aluminum

As aluminum is welded with AC rather than DC mode, the electrical characteristics are different compared to welding mild steel and the amount of energy put into the tungsten electrode is higher when AC welding. For these reasons, pure tungsten, Zirconiated or 2% Ceriated tungsten are recommended for aluminum welding. Although 2% Thoriated tungsten can be used, this electrode contains thorium, a radioactive material that can pose health and environmental risks at elevated exposure levels. Thorium is a low-level radioactive material that primarily emits alpha particles as well as some beta and gamma radiation. It is for this reason that is falling out of favor in the welding industry.

In addition, the electrode diameter for AC welding has to be significantly larger than when using DC. It is recommended to start with an electrode that is 1/8" and adjust as needed. Zirconiated tungsten can carry more current than pure tungsten electrodes. Another helpful hint for AC welding is to use a blunt tip - the arc tends to wander around a pointed tip.

BASE METAL TYPE	THICKNESS RANGE	DESIRED RESULTS	WELDING CURRENT	ELECTRODE TYPE	SHIELD GAS	TUNGSTEN PERFORMANCE CHARACTERISTICS
ALUMINUM ALLOYS AND MAGNESIUM ALLOYS	All	General Purpose	ACHF	Pure (EW-P)	Argon	Balls easily, low cost but tends to split at thigher currents. Is used for non-critical welds only.
				Zirconiated (EW-Zr)	Argon	Balls well and takes higher current with less splitting. Better arc starts and stability the pure tungsten
				2% Thoriated (EW-Th2)	75% Argon 25% Helium	Higher current range and stability. Better arc starts with lower tendency to split. Medium erosion.
	Only Thin Sections	Control Penetration	DCRP	2% Ceriated (EW-Ce2)	Argon Helium	Lowest erosion rate, widest current range. AC or DC. Has no splitting with best arc starts and stability
	Only Thick Sections	Increase Penetration or Travel Speed	DCSP	2% Thoriated (EW-Th2)	75% Argon 25% Helium	Best stability at medium currents and good arc starts. Medium tendency to split, and medium erosion rate
				2% Ceriated (EW-Ce2)	Helium	Low erosion rate, wide current range. AC or DC. Has no splitting, consistent arc starts and good stability.

Preheating aluminum parent material

While a little preheat is good, too much preheat can degrade the mechanical properties of the aluminum.

Normally, the last heat treatment for heat treatable alloys is 400°F, and even if the preheat and interpass welding temperature of the aluminum is 350°F, the aluminum's mechanical properties are changed.

For the non-heat treatable alloys such as the 5000 series, even if the temperature is kept as the 200°F range, material can still be sensitized to stress corrosion cracking. Thus, some preheat is acceptable to dry the moisture away from the parent material, but preheat should be limited.

Preheat is sometimes used as a crutch. As equipment for welding aluminum needs to operate at higher capacities, many feel that preheat helps eliminate equipment limitations, but this is not the case. Aluminum has a low melting point of ~1200°F compared to mild steel at ~2600°F. Because of this low melting point, many operators believe that only light duty equipment is required to weld the aluminum. But, the thermal conductivity of aluminum is five times that of mild steel, which means that the heat dissipates much faster. Therefore, welding currents and voltages for welding aluminum are higher than they are for steel, and heavier duty equipment is required when welding aluminum.

Stress relieving practice for aluminum welds

Welding causes residual stresses around the vicinity of the weld because the molten material shrinks as it solidifies. If machining is then required, it can distort and create dimensional instability. To avoid this, stress relieving can be done by heating the material hot enough to allow the aluminum atoms to move around. The proper stress relieving temperature is 650°F. But this means that in order for post weld stress relief on aluminum to be effective, the material will have to be heated to a temperature where mechanical properties will be lost.

For this reason, post weld stress relief is not recommended for aluminum.

How to determine what aluminum alloy you have

There are quite a few different aluminum alloys and for proper and safe welding, you should know what alloy you are welding. If you don't, you can follow these general guidelines:

Extrusions	-are generally 6000 series alloys.
Castings	-most often are a combination of aluminum/silicon cast. Some are weldable, others are not.
Sheet	-are probably 5000 to 6000 series alloys
Plate	-are probably 5000 to 6000 series alloys
Bar Stock	-are probably 5000 to 6000 series alloys

If you need to be precise, purchase an alloy tester kit that will help you determine the exact makeup of your alloy.

TIG welding of dissimilar thicknesses of aluminum

When joining two dissimilar thicknesses of aluminum, set the parameters so that they are high enough to weld the thickest piece. When welding, put more of the heat on the thicker piece.

GUIDE TO THE CHOICE OF FILLER METAL FOR GENERAL PURPOSE WELDING OF ALUMINUM

BASE METAL	201.0 206.0 224.0	319.0, 333.0, 354.0, 355.0, C355.0	356.0, A356.0, 357.0, A357.0, 413.0, 443.0, A444.0	511.0, 512.0, 513.0, 514.0, 535.0	7004, 7005, 7039, 710.0, 712.0	6009 6010 6070	6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	5456	5454	5154 5254 (i)	5086	5083	5052 5652 (i)	5005 5050	3004 Alc. 3004	2219	2014 2036	1100 3003 Alc. 3003	1060 1070 1080 1350
1060, 1070, 1080, 1350	ER4145	ER4145	ER4043 (a,b)	ER5356 (c,d)	ER5356 (c,d)	ER4043 (a,b)	ER4043 (b)	ER5356 (d)	ER4043 (b,d)	ER5356 (c,d)	ER5356 (d)	ER5356 (d)	ER4043 (b,d)	ER1100 (b,c)	ER4043 (b,d)	ER4145 (b,c)	ER4145	ER1100 (b,c)	ER1188 (b,c,h,j)
1100, 3003, Alc 3003	ER4145	ER4145	ER4043 (a,b)	ER5356 (c,d)	ER5356 (c,d)	ER4043 (a,b)	ER4043 (b)	ER5356 (d)	ER4043 (b,d)	ER5356 (c,d)	ER5356 (d)	ER5356 (d)	ER4043 (b,d)	ER1100 (b,c)	ER4043 (b,d)	ER4145 (b,c)	ER4145	ER1100 (b,c)	
2014, 2036	ER4145 (e)	ER4145 (e)	ER4145	-	-	ER4145	ER4145	-	-	-	-	-	-	ER4145	ER4145	ER4145 (e)	ER4145 (e)		
2219	ER2319 (a)	ER4145 (e)	ER4145 (b,c)	ER4043	ER4043	ER4043 (a,b)	ER4043 (a,b)	-	ER4043 (b)	ER4043	-	-	ER4043 (b)	ER4043 (a,b)	ER4043 (a,b)	ER2319 (a)			
3004, Alc 3004	-	ER4043 (b)	ER4043 (b)	ER5356 (f)	ER5356 (f)	ER4043 (b)	ER4043 (b,f)	ER5356 (d)	ER5356 (f)	ER5356 (f)	ER5356 (d)	ER5356 (d)	ER5356 (c,f)	ER5356 (c,f)	ER5356 (c,f)				
5005, 5050	-	ER4043 (b)	ER4043 (b)	ER5356 (f)	ER5356 (f)	ER4043 (b)	ER4043 (b,f)	ER5356 (d)	ER5356 (f)	ER5356 (f)	ER5356 (d)	ER5356 (d)	ER5356 (c,d)	ER5356 (c,f)					
5052, 5652 (i)	-	ER4043 (b)	ER4043 (f)	ER5356 (f)	ER5356 (f)	ER4043 (b)	ER5356 (c,f)	ER5356 (f)	ER5356 (f)	ER5356 (f)	ER5356 (d)	ER5356 (d)	ER5654 (c,f,i)						
5083	-	-	ER5356 (c,d)	ER5356 (d)	ER5183 (d)	-	ER5356 (d)	ER5183 (d)	ER5356 (d)	ER5356 (d)	ER5356 (d)	ER5183 (d)							
5086	-	-	ER5356 (c,d)	ER5356 (d)	ER5356 (d)	-	ER5356 (d)	ER5356 (d)	ER5356 (d)	ER5356 (d)	ER5356 (d)								
5154, 5254 (i)	-	-	ER4043 (f)	ER5356 (f)	ER5356 (f)	-	ER5356 (f)	ER5356 (f)	ER5356 (f)	ER5356 (f,i)									
5454	-	ER4043 (b)	ER4043 (f)	ER5356 (f)	ER5356 (f)	ER4043 (b)	ER5356 (c,f)	ER5356 (f)	ER5554 (c,f)										
5456	-	-	ER5356 (c,d)	ER5356 (d)	ER5556 (d)	-	ER5356 (d)	ER5556 (d)											
6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	ER4145	ER4145 (b,c)	ER4043 (b,f,g)	ER5356 (f)	ER5356 (c,f)	ER4043 (a,b,g)	ER4043 (b,f,g)												
6009, 6010, 6070	ER4145	ER4145 (b,c)	ER4043 (a,b,g)	ER4043	ER4043	ER4043 (a,b,g)													
7004, 7005, 7039, 710.0, 712.0	-	ER4043 (b)	ER4043 (b,f)	ER5356 (f)	ER5356 (d)														
511.0, 512.0, 513.0, 514.0, 535.0	-	-	ER4043 (f)	ER5356 (f)															
356.0, A356.0, 357.0, A357.0, 413.0, 443.0, A444.0	ER4145	ER4145 (b,c)	ER4043 (b,h)																
319.0, 333.0, 354.0, 355.0, C355.0	ER4145 (c)	ER4145 (b,c,h)																	
201.0, 206.0, 224.0	ER2319 (a,h)																		

(continued) -100

TYPICAL WELDING PARAMETERS OF ALUMINUM TIG & MIG WIRE

Process	Diameter of Wire: Inches	Diameter of Wire: Millimeters	Voltage (V)	Amperage (A)	Shielding Gas
TIG (GTAW)	1/16"	1.6		60-100	100% Argon
	3/32"	2.4		125-160	
	1/8"	3.2		180-240	
MIG (GMAW) SHORT CIRCUITING TRANSFER	0.030	0.8	15-18	45-120	100% Argon
	0.035	0.9	17-19	50-150	
	0.045	1.2	16-20	60-175	
MIG (GMAW) SPRAY TRANSFER	0.030	0.8	22-28	90-150	100% Argon 75% Argon 25% Helium
	0.035	0.9	22-28	100-175	
	0.045	1.2	22-28	120-210	
	1/16"	1.6	24-30	160-300	

Aluminum Temper Designation

The temper designation follows the cast or wrought designation number with a dash, a letter, and potentially a one to three digit number, e.g. 6061-T6.

F	As fabricated	T	Heat treated to produce stable tempers
H	Strain hardened (cold worked) with or without thermal treatment	T1	Cooled from hot working and naturally aged (at room temperature)
H1	Strain hardened without thermal treatment	T2	Cooled from hot working, cold-worked, and naturally aged
H2	Strain hardened and partially annealed	T3	Solution heat treated and cold worked
H3	Strain hardened and stabilized by low temperature heating	T4	Solution heat treated and naturally aged
	Second digit - A second digit denotes the degree of hardness	T5	Cooled from hot working and artificially aged (at elevated temperature)
	HX2 = 1/4 hard, HX4 = 1/2 hard, HX6 = 3/4 hard	T51	Stress relieved by stretching
	HX8 = full hard, HX9 = extra hard	T510	No further straightening after stretching
O	Full soft (annealed)	T511	Minor straightening after stretching
		T52	Stress relieved by thermal treatment
		T6	Solution heat treated and artificially aged
		T7	Solution heat treated and stabilized
		T8	Solution heat treated, cold worked, and artificially aged
		T9	Solution heat treated, artificially aged, and cold worked
		T10	Cooled from hot working, cold-worked, and artificially aged
		W	Solution heat treated only.

Note: -W is a relatively soft intermediary designation that applies after heat treat and before aging is completed. The -W condition can be extended at extremely low temperatures but not indefinitely and depending on the material will typically last no longer than 15 minutes at ambient temperatures.

GUIDE TO THE CHOICE OF FILLER METAL FOR GENERAL PURPOSE WELDING OF ALUMINUM (continued)

General Notes:
1. Service conditions such as immersion in fresh or salt water, exposure to specific chemicals, or a sustained high temperature (over 150oF [66oC]) may limit the choice of filler metals. Filler metals ER5183, ER5356, ER5556 are not recommended for sustained elevated temperature service.
2. Recommendations in this table apply to gas shielded arc welding processes. For oxyfuel gas welding, only ER1188, ER1100, ER4043, ER4047, and ER4145 filler metals are ordinarily used.
3. Where no filler metal is listed, the base metal combination is not recommended for welding.

Notes:
a. ER4145 may be used for some applications.
b. ER4047 may be used for some applications.
c. ER4043 may be used for some applications.
d. ER5183, ER5356, or ER5556 may be used.
e. ER2319 may be used for some applications. It can supply high strength when the weldment is postweld solution heat treated and aged.
f. ER5183, ER5356, ER5554, ER5556, and ER5654 may be used. In some cases, they provide: (1) improved color match after anodizing treatment, (2) highest weld ductility, and (3) higher weld strength. ER5554 is suitable for sustained elevated temperature service.
g. ER4643 will provide higher strength in 1/2in. [12mm] and thicker groove welds in 6XXX base alloys when postweld solution heat treated and aged.
h. Filler metal with the same analysis as the base metal is sometimes used. The following wrought filler metals possess the same chemical composition
i. Base metal alloys 5254 and 5652 are used for hydrogen peroxide service. ER5654 filler metal is used for welding both alloys for service temperatures below 150oF [66oC].
j. ER1100 may be used for some applications.