The responses below were provided to “Aluminum Now” by Warren Hunt Ph.D. and/or Lynne Karabin Ph.D. (Aluminum Consultants Group Inc. or Aluminum Consulting LLC)

The Aluminum Association provides information and resources about aluminum products and aluminum-related technology as a service to interested parties. Information provided by the Aluminum Association is generally intended for users with a technical background and may be inappropriate for use by laypersons. While the Aluminum Association makes every effort to disseminate the most reliable and current information available, the Aluminum Association does not warrant that the use of such information is appropriate for any particular purpose. In all cases, users should not rely on this information without consulting original source material and/or undertaking a thorough scientific analysis.

**How long will it take to naturally age 6061-T4 to a T6 condition?**

Data presented in *Aluminum: Properties and Physical Metallurgy, ed. J. E. Hatch, American Society for Metals, 1984* indicate that after 10 years of aging at room temperature, 6061-T4 material has not yet reached the ultimate tensile strength or tensile yield strength of the T6 temper.

Typically, artificial aging at a temperature between 320°F and 350°F is used to obtain the T6 temper in 6061. Even if one had the opportunity to wait more than 10 years to naturally age the material to those strength levels, the microstructures of the naturally aged and artificially aged materials would be expected to be quite different.

During artificial aging, the electrical conductivity of 6061 increases as the matrix becomes more and more depleted of solute as the precipitates grow. During room-temperature natural aging, the electrical conductivity of 6061 decreases, suggesting zone formation instead.

If you are interested in the publication *Aluminum: Properties and Physical Metallurgy*, you can order it by calling (301) 645-0756 or by visiting the Aluminum Association BookStore at [www.aluminum.org/bookstore](http://www.aluminum.org/bookstore).

**Will there be a difference in thermal expansion for aluminum given various surface treatments?**

Any difference in thermal expansion will be due to the difference in temperatures that the particular surfaces reach. According to the *Aluminum Design Manual-2005, p. IX-29, section 4.1:

"Solar radiation can develop material temperatures of 140°F on bare aluminum and up to 180°F on dark painted metal.”

The appropriate equation to calculate thermal expansion is: \( \Delta L = \alpha \Delta T L \)

Where:

- \( \Delta L \) = the change in length
- \( \alpha \) = the thermal expansion coefficient
- \( \Delta T \) = the temperature range
- \( L \) = the original length

Using a thermal expansion coefficient of 13 x 10-6 per °F, this 40°F difference in temperature translates to a difference in thermal expansion of almost 0.2 inches over a 30-foot length.

However, it is important to consider the entire expected thermal excursion. Bare aluminum may see a total thermal excursion of 150°F, assuming a minimum of –10°F and a maximum of 140°F. By the same reasoning, dark painted metal may see a total thermal excursion of 190°F. Therefore, 30-foot lengths of bare and dark painted aluminum should be designed with expansion allowances of about 0.70” and 0.90”, respectively.
Tech Q&A taken from “Aluminum Now” Magazine

Are there guidelines for how best to keep copper and aluminum apart to avoid corrosion?

There are two types of corrosion to consider: that from run-off from the copper and galvanic corrosion. Both can be adequately addressed by painting the copper.

The Aluminum Design Manual-2010 (The Aluminum Association, 2010) discusses run-off from heavy metals, and section M.7.4 states: “Aluminum shall not be exposed to water that has come in contact with a heavy metal such as copper. The heavy metal shall be painted or coated, or the drainage from the metal diverted away from the aluminum, or painted aluminum shall be used.”

To minimize galvanic corrosion, you always want to maximize the size of the anode and minimize the size of the cathode. In an aluminum/copper couple, copper is the cathode and aluminum is the anode. If you paint the copper and the paint gets scratched, then you have a small cathode and a very large anode, which is exactly what you want. (If you instead paint the aluminum and it gets scratched, then you have a small anode and a very large cathode, which is not what you want.)

In order to minimize springback, should we bend our 5052-H32 sheet along the grain direction or against it?

As long as there are no residual stresses in your sheet, the direction should not affect the amount of springback, because tensile properties of 5052-H32 are fairly isotropic.

The amount of springback is related to the slope of the stress-strain curve (i.e., the elastic modulus) and the amount of elastic strain that has been accomplished, the latter of which is affected by the yield strength. For a given elastic modulus, the higher the yield strength, the greater the amount of elastic strain and, hence, the greater the amount of springback. The elastic modulus is not direction-dependent and if there is a difference in yield strength in the longitudinal and transverse directions, it is quite small. So, the bend direction with respect to the rolling direction should not affect the amount of springback.

If you have a material with very different longitudinal and transverse yield strengths, you might expect a notable difference in the amount of springback when bending across the two different directions.

There may be a reason to take bends across the grain direction, rather than with it, in cases where ductility is an issue.

We are producing window frames for use in a highly corrosive salt environment. We need an alloy which is fairly strong and very corrosion resistant. We understand that 6061-T6 or 6063-T5 can be used and want to know which would be better for our application.

There is a basic trade off between strength and corrosion resistance with the two alloys you’ve mentioned. While 6063-T5 gets an A rating for general corrosion resistance, 6061-T6 gets a B. The test is based on exposure to sodium chloride solution by intermittent spraying or immersion. Alloys with A and B ratings can be used in industrial or seacoast atmospheres without protection. For 6063-T5 in thicknesses up through 0.500", the minimum yield strength is 16.0 ksi and the minimum ultimate tensile strength is 22.0 ksi. For 6061-T6, the minimum yield strength is 35.0 ksi and the minimum ultimate tensile strength is 38.0 ksi.

For windows, 6063 is often chosen. Sometimes 6061 would be chosen because of its higher strength, but it would probably not be chosen if the intent is to anodize because 6061 doesn’t anodize as well as 6063.

I am interested in obtaining information on preparing and painting an aluminum boat.

The book, Boatbuilding with Aluminum, has a chapter on aluminum painting systems. That publication is available online at http://www.aluminum.org/template.cfm?Section=BookStore. The gist is that preparation and application are critical. Also, automotive paints are often used, and they provide an
attractive finish which will last a reasonable length of time. However, automotive paints are not appropriate for a boat that will be left in the water.

There are paint systems appropriate for marine applications. These systems have environmental impact, and therefore, there are national and local restrictions on their use. Because of these restrictions, special equipment is needed to apply some of them so it may be less costly to let a professional boat shop do the work if you choose one of those types.

If you do select a system that you can apply yourself, you will need to mechanically prepare the surface (by sanding or abrasive pads), etch (usually with phosphoric acid), apply primer, apply high-build barrier coats and apply hull finish paint. Each paint system manufacturer will have specific instructions. Sometimes, the manufacturer of the paint system will also offer technical assistance.

We are an anodizer of aluminum extrusions and occasionally have problems with white/gray spots, also called hot spots, on extrusions that can be seen on both sides of the metal. Is there anything we can do in the anodizing process to eliminate or minimize these?

Hot spots are usually associated with lower-hardness areas due to coarse precipitates caused by non-uniform cooling after extrusion. These regions appear after anodizing.

According to Parson et al., in "The Metallurgical Background to Problems Occurring During the Extrusion of 6xxx Alloys,” Proc. of the 5th International Aluminum Extrusion Technology Seminar, Vol. II, (The Aluminum Association and The Aluminum Extruders Council, 1992), hot spots are often observed in sections where there is localized contact with a carbon support block on the run-out table. Regions in contact with the carbon cool very rapidly momentarily and then are reheated from the adjacent mass of metal into a critical range for magnesium silicide precipitation.

Once the defect is formed, there is no way to eliminate it. The only solution is "to avoid contact between the hot extrusions and the run-out table for more than the shortest time necessary to carry out their removal to the lateral transfer table, where cooling to below the critical temperature range should be effected as fast as possible with fan-assisted air cooling. It is also helpful to use material other than carbon blocks, e.g., slats of material having a lower thermal conductivity than carbon, in construction of the run-out conveyer."

Would you provide cross-references to the following DIN 1725 standards: AlMg3, AlMg4.5, and AlMgSi0.5?

According to Aluminum-Schlussel: Key to Aluminum Alloys, 5th Edition (Dr. John Datta, published by Aluminum-Verlag Marketing and Kommunikation) in Germany, your designations correspond to the following international designations. Their cross-reference chart references DIN 1725.

AlMg3 = 3.3535 = 5754
AlMg4.5 = 3.3345= 5082
AlMgSi0.5= 3.3206 = 6060

Two other sources, Aluminum standards and data, 2006 Edition (The Aluminum Association, 2006) and Worldwide Guide to Equivalent Nonferrous Metals and Alloys (ed. W. C. Mack, ASM International, 1996) suggest that the German designation AlMgSi0.5 is equivalent to 6063 instead of the 6060 suggested above. Neither of these, however, reference DIN 1725 in particular. The ambiguity here points to the benefit of using the four-digit international designations.

We want to use 6061-T6 aluminum in a shrink-fit application. What temperature should be used?

To maintain T6 properties after shrink fitting, the process should be done at a temperature that would not reduce tensile properties. According to J. Gilbert Kaufman, Properties of Aluminum Alloys: Tensile, Creep, and Fatigue Data at High and Low Temperatures (ASM International and the Aluminum
Tech Q&A taken from “Aluminum Now” Magazine

Association, 1999) there is no loss in tensile properties after 0.5 h at 350°F and minimal loss after 0.5 h at 400°F.

Higher temperatures and/or longer times will lead to the reductions shown for 6061-T6, T651, and –T6511 (excluding sheet and rolled-and-drawn products) in the table below.

The average thermal expansion coefficient over the temperature range of 68°F to 212°F is 13.1 x 10-6 per °F for 6061. An adjustment in this value will be required if shrink fitting is done at 350°F to 400°F.

Data presented in Aluminum: Properties and Physical Metallurgy (ed. J. E. Hatch, American Society for Metals, 1984) on the effect of temperature on the thermal expansion coefficient of commercial purity aluminum indicate that the coefficient increased at 350°F to 400°F by about 12 to 14 percent compared to the room temperature value.

<table>
<thead>
<tr>
<th>Elevated Temperature Exposure</th>
<th>Typical Room Temperature Tensile Properties After Elevated Temperature Exposure</th>
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<tbody>
<tr>
<td>Exposure Temperature, °F</td>
<td>Exposure Time, h</td>
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<tr>
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<tr>
<td>350</td>
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<td>100</td>
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</tbody>
</table>

We have a 6061-T6 pipe with a 2” outside diameter and 1/8” thick wall. The pipe snapped readily in our bending operation. Could this have been anticipated?

Alloy 6063-T6 had been recommended but we were not able to find it. Should 6063-T6 pipe be more bendable than 6061-T6?

According to Table 1-8 of Forming and Machining Aluminum, the approximate minimum centerline bend radius is 4.25” for both 6061-T6 and 6063-T6 pipes with 2” outside diameters and 0.120” wall thicknesses, suggesting that 6063-T6 also may have failed in your process. For greater bendability, 6061-T4 or 6063-T4 pipes of the same size could be considered, as these are listed as having 3.375” minimum centerline bend radii. After bending, the pipes could be strengthened by artificial aging at 350°F. (Note all bend radius values assume use of a fully tooled draw-bending machine and ideal bending conditions, i.e., proper design and alignment of tools, smooth machine operation, and proper lubrication.)

If you are interested in ordering Forming and Machining Aluminum, you can do so by calling (301) 645-0756 or by visiting the Aluminum Association BookStore at: www.aluminum.org/bookstore.
I am looking for Izod test data for high-purity aluminum (>99.5%).

There are no Izod test data on any of the aluminum alloys in the Aluminum Association reference materials. This test is not considered to be a useful indicator of the fracture resistance of aluminum alloys. According to J. Gilbert Kaufman in *Fracture Resistance of Aluminum Alloys* (the Aluminum Association and ASM International, 2001), the Izod test is most useful in establishing the transition temperature below which fracture drops rapidly. Aluminum alloys do not have such a transition temperature so the test is of little value. Also, many aluminum alloys are so tough that they do not fracture completely in the Izod test. As a result, data from this test are not meaningful.

Notch tensile tests are recommended over Izod tests if sample limitation or other factors preclude true fracture toughness testing. Specifically, the notch-yield ratio (NYR), which is defined as the ratio of notch-tensile strength to tensile yield strength, is expected to be an indicator of the fracture toughness of a material.

If you are interested in the publication *Fracture Resistance of Aluminum Alloys*, you can order it by calling (301) 645-0756 or by visiting the Aluminum Association BookStore at: www.aluminum.org/bookstore.

Is there published information on the effect of strontium additions to A356.0 castings? We know that additions of sodium and calcium in the range of 0.015 percent to 0.030 percent modify the eutectic and wonder whether similar levels of strontium can be used.

Strontium is one of the elements known to produce eutectic modification in aluminum-silicon (Al-Si) castings. Modification refers to the replacement of coarse acicular Si crystals with a finer, more fibrous microstructure.

The fundamental mechanism of modification is to increase by orders of magnitude the number of crystallographic twins formed on the Si crystals during solidification. The increased twinning of the Si enables the fibers to bend and split to produce a substantially finer microstructure than in the unmodified alloy.

The effects of strontium (and sodium, antimony, and phosphorus) are discussed in detail in the book *The Treatment of Liquid Aluminum-Silicon Alloys* (John E. Gruzleski and Bernard M. Clossot, American Foundrymen’s Society, Inc., 1990). The amount of Sr needed depends on the Si level of the alloy. For example, 0.02 percent (by weight) is sufficient to modify alloy 356 which contains 7 percent Si, while 0.04 percent is needed for a eutectic alloy like 413 which contains 12 percent Si. Over modification will lead to a coarsened eutectic structure like that of the unmodified alloy, and strontium-containing intermetallic phases will appear. Higher addition levels are also associated with casting porosity and decreased degassing efficiency.

Strontium (Sr) is introduced via one of several available Al-Sr master alloys. It can be added with excellent recovery rates, but its dissolution can be complex. Those interested are referred to the above reference for a complete discussion on how best to incorporate the different master alloys.

The microstructural refinement of the modified alloy has been shown to produce higher ultimate tensile strength, higher ductility, higher impact strength, improved thermal shock properties, and increase hot tearing resistance when compared to the unmodified alloy. Improvement in fatigue strength has not been documented.

Sodium (Na) is a more powerful modifier than Sr, but it can add hydrogen to the melt and it tends to fade more quickly than Sr, i.e., its level in the melt decreases with time because of oxidation. Also, Sr is not particularly effective at low solidification rates. There are benefits to using Na and Sr together, sodium being most effective at short times and Sr improving the structure with time. These are documented in the book *Aluminum Alloy Castings: Properties, Processes and Applications* (J. Gilbert Kaufman and Elwin L. Rooy, ASM International and the American Foundry Society.), which is available from the Aluminum Association BookStore at: www.aluminum.org/bookstore.
How fast does a fresh extrusion of 6063 oxidize and how thick will that oxide coating get?

The natural oxide forms readily since the reaction of elemental aluminum with oxygen is highly exothermic. According to Karl Wefers, in "Oxides and Hydroxides of Aluminum", Alcoa Laboratories, 1987:

"Oxide layers developing near room temperature in oxygen or dry air reach a limiting thickness of 2 to 4 nm after several hours."

If the oxide is formed at higher temperatures, it will be thicker. According to Surface Treatment and Finishing of Aluminum and Its Alloys (S. Wernick, R. Pinner, and P. G. Sheasby, 5th edition, ASM International and Finishing Publications, 1987) the natural oxide formed at temperatures above 300°C can be up to 30 nm thick.

The oxide coating should be fairly uniform. Kinetics of oxide growth are complex. Temperature and moisture content of the atmosphere will influence these so it is difficult to say how thick the oxide will become.

I am interested in finding out how to heat treat a brazed assembly of 6013-T6 and 6061-O to achieve the T6 condition.

According to AMS2770 “Heat Treatment of Wrought Aluminum Alloy Parts,” the heat treating conditions for the individual products are as follows:

6013-T6: solution heat-treat at 1055°F. Quench. Naturally age at room temperature at least 336 hours. Age 4 to 5 hours at 375°F.

6061-T6: solution heat treat at 985°F. Quench. Age 8 to 10 hours at 350°F.

Clearly, you cannot optimize both products using one treatment. Your heat treatment temperature will need to be limited to 985°F in order to be sure to avoid any undesirable melting reactions.

For complete heat treating details, you can obtain this specification from the SAE International website, at www.sae.org.

If the composition limits on magnesium are 0.20 to 0.8% for a particular wrought alloy and the actual spectrometer result is 0.8055%, does the material conform?

You must apply ASTM E29 rounding rules and round the number to the appropriate significant digit of the magnesium specification. The 0.8055 would be rounded to 0.8, and therefore the material would conform to the specification. (If the limit on magnesium had been given as 0.80%, then the 0.8055 would have been rounded to 0.81 and the alloy would not conform.)

What is the best way to protect automotive aluminum from experiencing filiform corrosion?

According to Aluminum for Automotive Body Sheet Panels (the Aluminum Association, 1998) many 2xxx, 5xxx, and 6xxx automotive body sheet alloys tested performed satisfactorily with respect to filiform corrosion (and other performance requirements) when finished using a phosphating process followed by electrocoating. The publication describes the major steps in the finishing process: cleaning, rinsing, phosphate conditioning, phosphating, rinsing, electrocoating, baking, priming, topcoating, and baking again.

Of course, exact performance depends on the particular alloy, quality of the pretreatment, and other factors. You can download this publication for free at: www.autoaluminum.org/main/index.cfm?secID=33&ArticleID=33. There is also discussion of filiform corrosion in Corrosion of Aluminum and Aluminum Alloys (J. R. Davis, ASM International, 1999), which can be ordered through the Aluminum Association BookStore at www.aluminum.org/bookstore.
I have recently heard of precision tolerances. Do these replace standard tolerances and, if so, when did this change go into effect?

Precision tolerances for extrusions were an addition to ANSI H35.2 –American National Standard Dimensional Tolerances for Aluminum Mill Products and Aluminum standards and data that occurred with the 2006 editions of both of those documents. The published precision tolerances document what had been broadly understood in the industry, i.e., that many producers may be able to supply extrusions with tighter than-standard tolerances.

Prior to the introduction of the precision tolerances, a user could negotiate ahead of time with the producer to get tighter-than-standard tolerances. Now, the user can request either the standard tolerances or the precision tolerances, and these documents will show what tolerances should be expected. Precision tolerances may not be available for all profiles or from all suppliers, and some products may be available in tolerances tighter than those published. The user should contact individual producers about what tolerances are available.

The 2009 revisions of both publications are available from the Aluminum Association BookStore at www.aluminum.org/bookstore.

What methods are used for testing aluminum foil?

For tension testing, the specification ASTM E345 "Tension Testing of Metallic Foil" should be used, as modified by procedures outlined in Aluminum standards and data, 2003 Edition. The ASTM specification can be obtained through the American Society for Testing and Materials at www.astm.org. Aluminum Standards and Data, 2003 Edition can be obtained through the Aluminum Association’s BookStore at www.aluminum.org/bookstore.

Tension testing of foil requires special precautions since the results can be affected by rough specimen edges, slight scratches, test speed, test machine alignment and other variables. If the foil is less than 0.0007 inches in thickness, special agreements must be made between vendor and purchaser.

Tension test specimens from foil may be machined or sheared, but they must be examined at 20X magnification to be sure that edges are smooth. Specimen thicknesses for foils 0.002 inches and thinner are determined by weighing to an accuracy of 2 percent. An optometer is used for thicker foils. Specimen widths are recorded to the nearest 0.001 inch.

If only the ultimate tensile strength is determined, the strain rate should be between 0.06 and 0.5 inch/inch of gauge length/minute. If yield strength is also determined, the strain rate should be 0.002 to 0.010 inch/inch or gauge length/minute until after reaching the yield strength. Average values of duplicate tests should be reported.

We are used to forming a particular part from 0.063" thick 2024-T3 sheet. The part is 58" long, but we are having trouble locating a piece wide enough to orient the length of the part along the width of the sheet. We need to make bends across the length of the part having 0.250" minimum bend radii. If we purchase 48" wide sheet and orient the length of the part along the longitudinal direction of the sheet, can we be assured that we will be able to make the same bends that we had been making when we had oriented it 90 degrees apart?

It seems likely that you will have problems if you try to achieve the same bends with the new orientation necessitated by the narrow sheet. As noted in ASM Specialty Handbook: Aluminum and Aluminum Alloys, ed. J. R. Davis, ASM International, 1993, p. 235, typically, the most severe bends can be made across the direction of rolling.

Previously, you have been taking advantage of the grain direction by orienting the length of your part along the width of the sheet and making your bends across the direction of rolling. According to Forming and Machining Aluminum, the tabulated approximate bend radii for 0.063" thick 2024-T3 sheet is 0.250". That reference suggests that design radii be 50 percent larger than the tabulated value in order to accommodate the entire range of production. If you change the orientation of your part to use the narrow
What is the thickness and tensile strength of standard household aluminum foil?

What is the thickness tolerance?

Typical foil gauges are 0.00065 in. for standard, 0.00095 in. for heavy duty, and 0.0015 in. for extra heavy duty foil.

ASTM B479 Standard Specification for Annealed Aluminum and Aluminum-Alloy Foil for Flexible Barrier, Food Contact, and Other Applications includes several foil alloys: 1100, 1145, 1235, 8079 and 8111. The standard gives tensile breaking loads as a function of foil thickness in units of pounds per inch of width. If divided by the thickness, the tensile strength varies from about 6200 psi to 6500 psi. Instead of tabulating thickness tolerances, this standard gives minimum, nominal, and maximum covering areas which are based on a standard thickness tolerance of +/- 10 percent.

Is the 5083-H321 alloy/temper product equivalent to 5083-H116 or to 5083-H32?

Footnote 8 of Aluminum standards and data, 2009 Edition, p. 3-11 states: "5xxx products in the -H116 and -H321 tempers have similar properties and have the same testing requirements, but are produced by different practices. The -H116 and -H321 tempers are typically used in marine and other applications requiring demonstrations of intergranular and exfoliation corrosion resistance. Products in the -H32 temper have similar tensile properties and while production methods may be similar, corrosion testing requirements are different; therefore, the -H32 temper products shall not be substituted for -H116 or -H321 products."

If you are interested in Aluminum standards and data, 2009 Edition, it can be ordered from the Aluminum Association BookStore at: www.aluminum.org/bookstore.

In what form is silicon added to molten aluminum to produce (primary or secondary) silicon-containing aluminum alloys?


"Silicon is used in "foundry alloys" (silumines) as it gives excellent fluidity in casting. It is also used in extrusion alloys, to which it contributes high mechanical properties. The main method of addition is as a pure metal, but significant amounts are added as master alloys and through powder injection."

What alloy is used in aluminum beverage cans and what are its properties?

Beverage can bodies are typically 3004 or 3104 in the H19 temper. The 3004-H19 has a typical tensile yield strength of 41.3 ksi, a typical ultimate tensile strength of 42.8 ksi, and an elastic modulus of 10.0 Msi. The ends are typically 5182-H19. The 5182-H19 has a typical tensile yield strength of 57.3 ksi, a typical ultimate tensile strength of 60.9 ksi and an elastic modulus of 10.1 Msi.

I'm working on a project where I need to use copper-free, 0.050” to 0.063” thick aluminum sheeting to fabricate some protective guards for rotating machinery. The equipment will be placed on an offshore oil platform where it will be exposed to seacoast air. Can you recommend a grade of copper-free aluminum that could be bent into a "box" shape for this application? I had thought of 6061-T6, but I don't know if that is classified as copper-free.

The limits on copper in 6061 are 0.15 to 0.40 weight percent, which means that copper is intentionally added and, therefore, it would not be considered copper-free. Even when copper is not intentionally added to an alloy, a certain amount is permitted to be there.
Some common sheet alloys used in building construction that do not contain intentional additions of copper are:

- 3004 (0.25 wt. % copper max. allowed)
- 3105 (0.30 wt. % copper max. allowed)
- 5005 (0.20 wt. % copper max. allowed)
- 5052 (0.10 wt. % copper max. allowed)

Those alloys are commonly used in H14 or H34 type tempers. Typical tensile properties and the minimum bend radii for 90-degree cold forming from *Aluminum Standards and Data, 2009 Edition* are shown in the table on the next column for these candidates. Note that tighter bends can be taken for the softer alloy/tempers.

<table>
<thead>
<tr>
<th>Alloy/Temper</th>
<th>Typical Tensile Properties</th>
<th>Minimum Bend Radii for 90 Degree Cold Forming*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ultimate Tensile Strength, ksi</td>
<td>Tensile Yield Strength, ksi</td>
</tr>
<tr>
<td>3004-H34</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>3105-H14</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>5005-H14</td>
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<tr>
<td>5005-H34</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td>5052-H34</td>
<td>38</td>
<td>31</td>
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</tbody>
</table>

*expressed in terms of the thickness, t.

N/A: data not available

All of the above choices have excellent general corrosion resistance. They are given “A” ratings based on exposures to sodium chloride solution by intermittent spraying or immersion—meaning they can be used in industrial and seacoast atmospheres without protection.

If you are interested, you can order the publication alluded to earlier by calling (301) 645-0756 or going online at [www.aluminum.org/bookstore](http://www.aluminum.org/bookstore).

**What degree of acidity will aluminum withstand?**

The natural protective oxide film on aluminum is normally stable in aqueous solutions having a pH between 4.0 and 9.0. The pH alone, however, does not dictate the corrosion rate. Corrosion rates are influenced by the particular acid or base.

According to J. E. Hatch, *Aluminum: Properties and Physical Metallurgy, American Society for Metals, 1984*, for a given pH, hydrofluoric acid and phosphoric acid cause very high corrosion rates of 1100-H14 while the same material is very resistant to corrosion by acetic acid. Hydrochloric, nitric and sulfuric acids are intermediate in their rates of attack.
Temperature will also affect rates of corrosion. For example, boiling anhydrous acetic acid is very corrosive to aluminum. And, inhibitors can be used to reduce the corrosivity of hydrochloric, nitric and phosphoric acids. The Aluminum Association’s publication *Guidelines for the Use of Aluminum with Food and Chemicals* provides compatibility data for aluminum with various chemicals.

If you are interested in this publication, it can be ordered by calling (301) 645-0756, and is also available online at [www.aluminum.org/BookStore](http://www.aluminum.org/BookStore).

**What are the theoretical burst pressures for 2” Schedule 80 and 2” Schedule 160 6061-T6 pipe?**

Section 3.12 of the *Aluminum Design Manual-2010* cites the following equation to estimate pipe bursting pressure, P:

\[
P = \frac{2 \ t \ F_{tu} \ K}{(D - 0.8 \ t)}
\]

Where:

- \( t \) = pipe wall thickness
- \( F_{tu} \) = tensile ultimate strength
- \( K = 0.73 + 0.33 \frac{F_{ty}}{F_{tu}} \)
- \( D \) = pipe outside diameter
- \( F_{ty} \) = tensile yield strength

The Aluminum Association publication *Aluminum Standards and Data, 2009 Edition* lists the following dimensions for pipe.

For 2” nominal schedule 80 pipe:

- nominal outside diameter: 2.375”
- nominal wall thickness: 0.218”

For 2” nominal schedule 160 pipe:

- nominal outside diameter: 2.375”
- nominal wall thickness: 0.344”

The same reference lists the minimum tensile properties for 6061-T6:

- ultimate tensile strength: 38 ksi
- tensile yield strength: 35 ksi

Based on the above equation and these properties, the nominal burst pressures are about 8,000 psi and 13,000 psi for schedules 80 and 160, respectively. The appropriate safety factor will depend on the application.

**Can aluminum be welded to stainless steel?**

Aluminum cannot be welded to stainless steel using standard fusion methods because brittle intermetallics will form; however, there are special techniques that can be used.

- Bimetallic transition inserts are available in aluminum/stainless steel combinations. The aluminum portion of the insert is first welded to the aluminum, typically using gas metal arc welding (GMAW) rather than gas tungsten arc welding (GTAW), since the former uses higher speeds than the latter, thereby minimizing the heat into the piece. The steel weld is done second.
The stainless steel can be coated with aluminum and then welded by either GMAW or GTAW provided that care is taken to prevent the arc from impinging on the steel.

Solid state welding techniques like explosion welding, ultrasonic welding, diffusion welding, hot pressure welding, and friction welding avoid the formation of brittle intermetallics and have been used to join aluminum and stainless steel.

The Aluminum Association publication *Welding Aluminum: Theory and Practice* includes a chapter on welding aluminum to other metals. If you are interested in this publication, it can be ordered by calling 301-645-0756 or online at [www.aluminum.org/bookstore](http://www.aluminum.org/bookstore).

**Can a wrought alloy like 6061-T6 be annealed to remove the temper to form or shape and then be re-tempered to T6 without damaging the alloy? Is this a common industrial practice?**

If you have 6061-T6, you can remove the effects of heat treatment by annealing it at 775°F for 2 to 3 hours. The part should be cooled at a rate of about 50°F per hour from the annealing temperature down to 500°F, but the rate of subsequent cooling is not important.

To re-temper it, you would need to solution heat treat, cold water quench, and then artificially age. For sheet and plate products, the typical solution heat-treat temperature is 990°F, and a typical aging practice would be 18 hours at 320°F. For other products, the aging time and temperature will vary somewhat.

This practice is not common for several reasons. First, parts would need to be properly supported during solution heat treatment to avoid deformation of the part under its own weight, and distortion of the formed part would likely occur during quenching. Second, it may not be cost effective to incur heat treating costs for a second time. Finally, the second solution heat treat practice may cause some grain growth or grain structure changes, which may or may not be a problem, depending on your application.

The best way to achieve a formed part of 6061-T6 would be to begin with 6061-T4, form it, and then age it to the T6 temper. The T4 temper is considerably more formable than the T6 temper.

**I have spilled wood stain on my aluminum siding and unfortunately it dried before it was noticed. I have tried all sorts of household cleaners with no success. What can I use to remove that stain?**

The Aluminum Association publication *Care of Aluminum* describes in detail how to clean aluminum of various finishes. It says that (1) mild soaps, detergents and non-etching cleaners, (2) solvent and emulsions and (3) moderate duty abrasives could be suitable for painted finishes but they must be spot tested first. Examples of cleaners in the first category are Mr. Clean, Spic-N-Span Liquid, Dawn, Joy, Ivory Liquid, and Cascade.

Examples of solvent and emulsions are Airshow W, Expedite, Cee Bee C-50 and Magnusol 729. An example of a moderate duty abrasive would be Ajax. The three categories of cleaners are listed in the order of increasing ability to remove stains and weathering. If the mild soaps, detergents and non-etching cleaners have not worked, you should move on to the solvent and emulsion types. If those do not work, try the moderate duty abrasive.

*Note:* The inquirer called back to verify that Ajax did remove the wood stain from the siding.

**Which aluminum alloys can be autogenously welded using the gas tungsten arc welding (GTAW) method?**

Welding without using a filler alloy is called autogenous welding. According to *Welding Aluminum: Theory and Practice*, autogenous welding by the GTAW method can be used for edge and corner welds and also for automatic butt welding of light gauge sheet, but it should be limited to alloys that are not prone to hot cracking. The 1xxx and 3xxx alloys are not prone to hot cracking. Most of the 5xxx alloys can be autogenously welded with the exception of some lower Mg 5xxx alloys, such as 5052, where
cracking difficulties are reported. Also, most 2xxx, 6xxx and 7xxx alloys are prone to hot cracking, but there are exceptions such as some of the 7xxx alloys with lower copper (e.g. 7004, 7005, 7039) that are less so.

If you are interested in this publication, it can be ordered online at: http://www.aluminum.org/Template.cfm?Section=BookStore&Template=/Ecommerce/ProductDisplay.cfm&ProductID=321.

We manufacture hydraulic valves from 3” to 4” thick plates of 6061-T6 but need something tougher. Is 7075-T6 an alternative?

Although 7075-T6 is substantially stronger than 6061-T6, it is not tougher. According to J. Gilbert Kaufman, *Fracture Resistance of Aluminum Alloys* (Aluminum Association and American Society for Metals, 2001, p. 102), published typical KIC values for L-T specimens from 6061-T651 and 7075-T651 plate are 35 and 26 ksi sq.rt. inch, respectively.

How are aluminum metal matrix composites designated with the Aluminum Association?

In aluminum metal matrix composites, a reinforcing phase (typically a ceramic particle, whisker, or fiber) is added to the aluminum to modify its properties, but the reinforcement is not considered an alloying element for purposes of the Aluminum Association designation. Instead, the composite is designated in a different way. As an example, a 6061-T6 aluminum alloy reinforced with 20 percent by volume of silicon carbide particles would be designated 6061/SiC/20p-T6. The complete description of this designation system is included in ANSI standard H35.5, which can be obtained from the Aluminum Association BookStore at www.aluminum.org/BookStore.

When was the four-digit designation system for aluminum alloys created? Do other countries use the Aluminum Association’s system? Where can I get a list cross referencing former designations and the current four-digit ones?

According to *Introduction to Aluminum Alloys and Tempers*, by J. Gilbert Kaufman, ASM International, 2000:

“The alloy and temper designation systems for wrought aluminum that are in use today were adopted by the aluminum industry around 1955, and the current system for the cast aluminum system was developed somewhat later.”

The text further notes:

“...the Aluminum Association designation system is the basis of the ANSI standards, incorporated in ANSI H35.1 and, for the wrought alloy system at least, forms the basis for the nearly worldwide International Accord on Alloy Designations.”

The same reference provides a table comparing previous and current designations for the most common wrought alloys. Below is an excerpt from that table.

<table>
<thead>
<tr>
<th>Old Designation</th>
<th>Current Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1S</td>
<td>1100</td>
</tr>
<tr>
<td>3S</td>
<td>3003</td>
</tr>
<tr>
<td>4S</td>
<td>3004</td>
</tr>
<tr>
<td>14S</td>
<td>2014</td>
</tr>
<tr>
<td>17S</td>
<td>2017</td>
</tr>
<tr>
<td>24S</td>
<td>2024</td>
</tr>
<tr>
<td>32S</td>
<td>4032</td>
</tr>
<tr>
<td>52S</td>
<td>5052</td>
</tr>
<tr>
<td>61S</td>
<td>6061</td>
</tr>
<tr>
<td>63S</td>
<td>6063</td>
</tr>
<tr>
<td>75S</td>
<td>7075</td>
</tr>
</tbody>
</table>
A list of cross references of international designations with the four-digit designations is included in the Association’s publication "International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys," which is available from the Aluminum Association BookStore at www.aluminum.org/BookStore.

**We are using 6061-T6 sheet in an application that requires subsequent forming and are having problems with cracking. We are thinking of buying 6061-T4, forming it and then aging it up to the T6 temper. Is this a reasonable plan and will we be assured of getting the same properties in the T6 material we prepare as we would have gotten in material that was originally in the T6 temper?**

Your plan is reasonable. The table below shows the minimum bend radii for a 90-degree cold bend in 6061 sheet and plate of various thicknesses.

<table>
<thead>
<tr>
<th>Sheet and Plate Thickness, in.</th>
<th>Minimum bend radius, expressed in terms of thickness, t</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/64</td>
<td>0</td>
</tr>
<tr>
<td>1/32</td>
<td>0</td>
</tr>
<tr>
<td>1/16</td>
<td>1 t</td>
</tr>
<tr>
<td>1/8</td>
<td>1-1/2 t</td>
</tr>
<tr>
<td>3/16</td>
<td>2-1/2 t</td>
</tr>
<tr>
<td>1/4</td>
<td>3 t</td>
</tr>
<tr>
<td>3/8</td>
<td>3-1/2 t</td>
</tr>
<tr>
<td>1/2</td>
<td>4 t</td>
</tr>
</tbody>
</table>

The radii shown here are minimums for the average mill products. To accommodate the entire commercial range of product, "design" radii should be 50 percent larger than the values shown. It is clear that 6061-T4 will be more formable than 6061-T6. (The data above were taken from the Aluminum Association publication *Forming and Machining Aluminum*, which is available from the BookStore at www.aluminum.org/bookstore.)

As for whether the properties will be the same for material that is formed in the T4 temper and then aged to T6 as compared to material that was initially purchased in the T6 condition, they should be quite close. The difference between the two materials is the natural aging interval between the quench from the solution heat treatment and the artificial aging step. This natural aging interval will affect the strength achieved.

In the case of the 2xxx and 7xxx alloys, some natural aging is generally necessary in order to achieve the best properties. In 6061, the highest strengths are obtained if the natural aging interval is minimized, but one should still meet the 6061-T6 tensile property minimums if some natural aging is allowed. The SAE specification AMS 2770 E "Heat Treatment of Wrought Aluminum Alloy Parts" shows in Table VI that an aging practice of 8 to 10 hours at 350°F will bring 6061-T4 up to 6061-T6.

Footnote 6 states: "When temper before aging is AQ, W, T4, or T42, aging treatment may be started immediately after quenching or any time thereafter." This statement indicates that you can form your material in the T4 temper and still meet minimum properties. However, if you are concerned about subtle
differences or differences in properties other than strength between the material that was formed in the T6 condition and the material that was formed in T4 before aging to T6, you will need to do some testing. (The AMS specifications are handled by the Society of Automotive Engineers. If you wish to order this specification, you can do so at www.sae.org.)