Street-Lighting Poles, Transmission Towers, and Station Structures

This book would be incomplete without a brief mention of the specialized structures related to the everyday use of aluminum electrical conductors.

Recent years have witnessed a steady gain in the use of aluminum for many types of structures required by the electrical industry. This is based on very sound considerations. Research programs have led to the development of high strength aluminum alloys, new effective structural designs and strong, economical fastening and joining methods. These factors, coupled with aluminum's traditionally known high resistance to corrosion, account for the wide use of aluminum structures today. We will discuss just a few of these in this chapter.

Aluminum Lighting Standards

A lighting standard is many things to many people.

It must be tall enough to cast its light from the luminaire it carries above any normal eye level and the angle of sighting along the thoroughfare.

It must be strong enough to resist high winds. On interstate highways it must be safe enough that its base breaks away when hit by a subcompact car at 20 mph.

It must be graceful in appearance and at the same time unobtrusive and uncluttered.

It must resist the effects of industrial and traffic induced corrosion for 25 years at least.

It must be designed to provide inherent concealment for transformer and wires or protective components and for easy cleaning of lenses and replacement lamps.

It must be versatile in that signs (either permanent or not) may be hung on the standard or flag poles provided at the top, or Christmas street decorations mounted from special brackets or used for a number of other accessories.

It must be low in installation and maintenance costs.

Aluminum, taking advantage of its good looks, light weight, high strength-to-weight ratio possibilities and high corrosion resistance has been accepted as an ideal material for street and highway lighting poles. This has been a steadily growing application of aluminum since the 1940's.

Aluminum lighting standards extend their versatility into highway safety by reducing vehicular damage and driver injury in collisions either as an intrinsic aspect of their design or by the simple installation of accessory breakaway devices.

Modern aluminum lighting standards are a combination of sheet, extruded and cast alloy sections. Shafts are usually 6063-T6 or 6005-T6 extrusions or 5086-H34 sheet; luminaire arms are 6061-T6 or 6063-T6 extrusions; bases and arm holders may be 356 casting alloy (Fig. 18-1).

Aluminum lighting standards can be designed with classic simplicity so that they may complement virtually every type of architectural or landscape background. Although aluminum has a pleasing appearance in its natural state, it can be made to take on a variety of finishes applied mechanically, chemically or electro-chemically. The surface can be polished, buffed or electro-brightened to give a wide range of interesting and attractive appearances. Through the anodizing process the natural surface oxide film can be deepened and strengthened to a substantial, hard refractory coating not only providing a very high degree of corrosion resistance but a surface that can also be impregnated with permanent coloring dyes.

With the high strength-to-weight ratios provided by these alloys, aluminum lighting standards form an assembly that is rugged enough for the severest service, yet light enough for installation crews to handle without special equipment.

Aluminum lighting standards are available for mounting luminaires up to 50 feet above the roadway with various arm configurations. (See Table 18-1).

Aluminum lighting standards may be of a tapered or uniform cross section. The former is fabricated by spin-tapering extruded 6063-T4 tubes about 1/8’’ per foot and then artificially aging to the T6 temper. The profile may also be fabricated from trapezoidal sheet sections pressformed and longitudinally welded into a tapered shaft. Uniform cross sectional lighting standards can be made in any cross sectional geometry with extrusions or press forming of sheet.
related structural applications of aluminum

Alloys and Temper

<table>
<thead>
<tr>
<th>Spun Aluminum Standard</th>
<th>Welded Tapered Sheet Aluminum Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>6063-T6, 6005-T6</td>
<td>5086-H34</td>
</tr>
</tbody>
</table>

Fig. 18-1. Typical street lighting standard using aluminum.
Aluminum Transmission Towers

Use of prefabricated metal towers for 138 kV and higher transmission is widespread today. However the traditional place held by steel in tower construction due to its high strength and relatively low cost is now being effectively challenged by selected high-strength aluminum alloys such as 6061-T6. The keys to this challenge are high strength-to-weight ratio, high corrosion resistance, multi-form shape extrudability and reasonably low, stable prices. The two factors of (1) dramatic reduction of installation costs and (2) virtual elimination of maintenance costs account in large part for the present serious consideration given to aluminum towers. Surfaces of aluminum transmission tower structures can be treated with various coatings to meet “non-glares” requirements often specified. These coatings need little or no maintenance in service.

Although aluminum cross-arms had been used in combination with steel towers for a complete transmission system before 1950, the first all-aluminum tower lines were placed into operation in 1959 by several utilities. These early aluminum towers were of the self-supporting type similar to existing steel tower designs. Structural angles in sizes from 2" x 2" x 3/16" to 10" x 10" x 1/4" and plates in thicknesses from 1/8" to 3/4" were employed using the excellent structural alloy 6061-T6.

Since pound for pound, aluminum represents a significantly higher metal cost than steel, it is to be expected that the shop-fabricated cost of an aluminum tower will be higher than for a comparable loading design in steel. This increase, however, can be fully offset in some cases because of lower field erection costs plus credit from much lower maintenance over the life of the structure. Also there are circumstances where interruptions of service for maintenance work cannot be tolerated; this factor alone justifies the use of aluminum.

Weight Reduction: Aluminum tower structures afford weight reductions of 50 to 75% from steel structures having equivalent capabilities.

This weight advantage of aluminum works as an important cost reduction factor in the construction of transmission towers. Lighter, conventional erection equipment can be used, as well as faster methods. Lightweight aluminum structurals can be assembled into components or complete towers at convenient locations, then transported easily and quickly to erection sites.

Still more time can be saved by using helicopters to transport components or even fully assembled towers.

With the many advantages of aluminum’s light weight, shorter schedules are easily met when installing any type of transmission line.

**Corrosion Resistance**: Pre-painting inspections, initial painting and subsequent upkeep repainting are unnecessary when aluminum structurals are used to build transmission towers. Dangers of repainting “hot line” towers (or the expense of de-energizing to make them safe) is avoided. Even without expensive painting and repainting, however, corrosion-resistant aluminum retains its good looks and remains structurally dependable longer than any other metal.

**Extrusion Design Capabilities**: As designers and users gained experience with aluminum towers, the advantages of special component shapes over conventional structural shapes became apparent. More opportunities in design innovation and economy are made available to the designer of transmission towers by aluminum than by any other material. Thus, the unique structural shapes into which aluminum can be extruded can be designed for optimum efficiency. Extrusion dies made to design specifications add only negligible amounts to the cost of the line system. Made-to-order steel members, on the other hand, would require highly expensive rolling equipment and operations.

With extruded aluminum structurals, maximum torsional rigidity and radii of gyration can be realized. And, since both assembly and erection are simpler with aluminum structurals, transmission lines can be designed more efficiently.

### Table 18-1

**Typical Aluminum Highway Light Standard Dimensions**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Double</td>
<td>Double</td>
<td>Double</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>26</td>
<td>6063</td>
<td>8 x 6 x 0.156</td>
<td>8 x 6 x 0.210</td>
<td>8 x 6 x 0.188</td>
<td>8 x 6 x 0.168</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6005</td>
<td>8 x 6 x 0.156</td>
<td>8 x 6 x 0.188</td>
<td>8 x 6 x 0.188</td>
<td>8 x 6 x 0.188</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5066</td>
<td>9 x 4.52 x 0.135</td>
<td>9 x 4.52 x 0.135</td>
<td>9 x 4.54 x 0.135</td>
<td>9 x 4.54 x 0.135</td>
</tr>
<tr>
<td>25</td>
<td>30</td>
<td>6063</td>
<td>8 x 6 x 0.210</td>
<td>10 x 6 x 0.188</td>
<td>10 x 6 x 0.188</td>
<td>10 x 6 x 0.312</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6005</td>
<td>8 x 6 x 0.156</td>
<td>8 x 6 x 0.156</td>
<td>10 x 6 x 0.170</td>
<td>10 x 6 x 0.198</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5066</td>
<td>9 x 4.06 x 0.135</td>
<td>9.1 x 4.17 x 0.188</td>
<td>9 x 4.46 x 0.135</td>
<td>9 x 4.59 x 0.188</td>
</tr>
<tr>
<td>40</td>
<td>35</td>
<td>6063</td>
<td>10 x 6 x 0.188</td>
<td>10 x 6 x 0.250</td>
<td>10 x 6 x 0.250</td>
<td>10 x 6 x 0.250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6005</td>
<td>10 x 6 x 0.156</td>
<td>10 x 6 x 0.170</td>
<td>10 x 6 x 0.170</td>
<td>10 x 6 x 0.170</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5066</td>
<td>12.5 x 7.58 x 0.125</td>
<td>13.6 x 7.59 x 0.125</td>
<td>13.6 x 8.01 x 0.135</td>
<td>13.5 x 8.01 x 0.135</td>
</tr>
<tr>
<td>45</td>
<td>40</td>
<td>6063</td>
<td>10 x 6 x 0.210</td>
<td>12 x 6 x 0.210</td>
<td>12 x 6 x 0.250</td>
<td>12 x 6 x 0.250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6005</td>
<td>10 x 6 x 0.156</td>
<td>12 x 6 x 0.210</td>
<td>12 x 6 x 0.198</td>
<td>12 x 6 x 0.210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5066</td>
<td>13.5 x 6.76 x 0.135</td>
<td>13.6 x 6.76 x 0.135</td>
<td>13.5 x 7.17 x 0.135</td>
<td>13.5 x 7.17 x 0.135</td>
</tr>
<tr>
<td>50</td>
<td>46</td>
<td>6063</td>
<td>10 x 6 x 0.250</td>
<td>12 x 6 x 0.250</td>
<td>12 x 6 x 0.312</td>
<td>12 x 6 x 0.312</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6005</td>
<td>10 x 6 x 0.170</td>
<td>12 x 6 x 0.210</td>
<td>12 x 6 x 0.312</td>
<td>12 x 6 x 0.312</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5066</td>
<td>13.5 x 5.92 x 0.135</td>
<td>13.5 x 5.92 x 0.135</td>
<td>13.5 x 6.34 x 0.135</td>
<td>13.5 x 6.34 x 0.135</td>
</tr>
</tbody>
</table>

*All dimensions are for poles designed for 80 mph wind load, except those marked with asterisk which are designed for 90 mph load.*
related structural applications of aluminum

easily and with less risk of problems in the field.

**Aluminum Transmission Tower Designs**

**Guyed “V” Towers** (Fig. 18-2): A guyed-V tower is basically two guy-supported vertical masts having a common footing and supporting a horizontal section for carrying electrical conductors and overhead ground wires. Design of a guyed-V tower is such that overturning moments are resisted by guy wires serving as tension members, and by latticed masts serving as compression members.

Guyed-V towers built with extruded aluminum structuralss average approximately 30% of the weight of self-supporting steel structures designed to the same performance specifications.

Because aluminum guy-supported line towers use guy wires as tension members, they weigh substantially less than equivalent aluminum self-supporting towers. (And the weight which has to be carried by the tower masts is reduced as the spread between the vertical masts and guy wires is increased. This spread, which represents the arm of the resisting moment, can be made as wide as the right-of-way will allow.)

**Guyed “Y” Towers** (Fig. 18-3): A guyed-Y transmission tower can be described as a guyed-V mounted on a guyed vertical mast. Like the V tower, the guyed-Y has 4 guy wires serving as tension members of its upper section. But it also has 4 guys stabilizing its lower, vertical section. These 4 lower, inside guys take shear from a guyed-Y tower at the junction point where the vertical mast meets the upper V section. Thus, the only shear load remaining on the tower foundation is that of the wind load on the slim vertical mast.

The guyed-Y tower, because of its unique geometry, has fewer members than a guyed-V. Furthermore, it has less column length—and the effect of wind on a long, unsupported column varies as the square of the length of the column. For tall towers, therefore, and for towers which will have to withstand heavy wind loads, the guyed-Y design will satisfy performance requirements at considerably lower cost than a guyed-V tower.

An aluminum guyed-Y transmission tower weighs considerably less than an equivalent guyed-V tower. And a guyed-V, for reasons noted on earlier pages, weighs less than an equivalent self-supporting tower.

Guyed-Y towers built with extruded aluminum structuralss weigh only 25%, on an approximate average, of self-supporting steel towers designed to same performance specifications.

**Guyed “Delta” Towers** (Fig. 18-4): This design has all the advantages inherent in the guyed “V” and “Y”. Having a single mast requiring fewer pieces, it is a very economical structure to assemble. The “Delta” configuration has an electrical and lower noise advantage over the flat and vertical configurations.

**Guyed “Gull Wing” Towers** (Fig. 18-5): This design is similar to the guyed “Delta” with further advantages in the unique design, increasing the spread of the guy wire attachments, minimizing the torsional forces and reducing guy tensions.

**Three-Pole Guyed Towers** (Fig. 18-6): Sharp angles in direction of a power transmission line pose problems best solved by the 3-pole tower. Recommended for lines having changes of direction greater than 15°, the 3-pole design provides a separate pole to support each phase of the line system.

Introduction of aluminum guyed “pole” transmission towers further refined this proven design. As with other 3-pole towers, each conductor on a 3-pole guyed aluminum transmission tower traverses the angle in the line supported by its own pole. Guy wires for the poles can be placed easily at those points where they will most effectively overcome the tangential forces created by the angles in the line.
Fig. 18-4. Guyed "Delta" aluminum structure on Southwestern Electric Power Company 345 kV line.

Fig. 18-3. Guyed "Y" aluminum structure on Louisiana Power & Light Company 500 kV line.
related structural applications of aluminum

An aluminum 3-pole guyed angle tower weighs approximately 20% of a self-supporting steel angle tower.

Guy-supported transmission towers have radically smaller bases than self-supporting towers. In terrain too difficult for locating conventional towers, therefore, the guyed tower—with its small footing and easily placed guy anchors—can be installed with relative ease.

Substantial savings in foundation costs are possible with guyed transmission towers. The central footing for a guyed tower need be designed for compression only; guy anchors, for uplift only. A self-supporting tower, on the other hand, requires costly multi-purpose foundations, designed for both compression and uplift.

Foundations on a self-supporting tower, in addition, are precisely interrelated—to each other and to the tower legs—and must be designed and installed with a high degree of exactness to avoid unnecessary stresses.

On a guyed tower, however, easily adjusted guys serve as tension members so that anchor points and central footing are not dependent on one another. Since each can be installed with little concern for the others, time and effort are saved and costs reduced.

Three types of foundations are generally used for guyed towers—galvanized grillage, pre-cast concrete and poured-in-place concrete. Screw anchors, piles and floating bases are also used.

Guyed transmission towers require no more right-of-way than equivalent self-supporting towers, since the towers' supporting guy wires require no greater width along the right-of-way—usually less than needed for mid-span blow-out of the conductors. This holds true with any design of guyed tower and regardless of whether the conductors are strung by V-strings or by single-string, free-swinging insulators.
Semi-Flexible Towers (Fig. 18-7): The semi-flexible transmission tower reflects a unique basic tower geometry. It is built with a transverse side as slender as stresses allow, thus is able to deflect under longitudinal loads produced at the conductor and ground wire attachment levels. Such deflection allows a portion of the unbalanced load to be carried by the other conductors or ground wires.

As a structural material, aluminum has far greater elasticity and flexibility than steel. In a semi-flexible transmission tower, this permits greater movement under given loading conditions than with steel. Economies in tower weight result as well as substantial savings in erection.

H-Frame Towers (Fig. 18-8): The “old reliable” H-frame transmission tower takes on new usefulness when constructed with extruded aluminum structural shapes. The aluminum version is similar in outline to X-braced wood pole structures but has columns and cross-arm assemblies that make maximum use of extruded shapes designed specifically for this application. It can be built not only taller than usual wooden pole H-frame towers but also stronger. Fewer towers are needed, therefore, for any given length of line. And fewer towers mean fewer sets of hardware in installation costs and fewer insulators to service and replace.

In H-frame towers, the economies inherent in aluminum because of its light weight and minimal maintenance needs are added to by generally lower material costs. This is especially so with line voltages through 345 kV, since tall wooden poles are continually becoming scarcer and more and more costly.

Variations of the all-aluminum H-frame include wooden poles with aluminum cross-arms and aluminum pole structures with wooden cross-arms. Two types of aluminum cross-arms are being used for this purpose. A single tube, 8 to 10 inches in diameter, 3/16 to 3/8 in. in thickness, of extruded 6061-T6 alloy makes a simple, strong, easily installed cross-arm. For the heaviest loadings, latticed cross-arms of extruded structural shapes in aluminum alloys are available.

Conventional Self-Supporting Towers: Overall weight reductions averaging 55 to 60 percent can be made by using extruded aluminum structural shapes instead of steel in building conventional, self-supporting types of transmission towers. When the design of a system calls for self-supporting towers—either 3-or 4-legged—the light weight of aluminum provides installation advantages at any tower site, but particularly at difficult, hard-to-reach locations. Fig. 18-8 is of a typical aluminum self-supported transmission tower (also called free-standing).
related structural applications of aluminum

Savings realized from aluminum’s minimal need for maintenance are especially pronounced on lines using self-supporting towers.

**Single Mast Self-Supporting Towers** (Fig. 18-9): This structure, designed for simplicity and limited right-of-way widths through urban or farm areas, has all the advantages inherent in an aluminum structure. The structure is designed using a rotating crossarm. Under minimal unbalanced longitudinal loads a pattern of bolts shears, allowing the arm to rotate reducing the longitudinal and torsional load on the mast and minimizing any domino effect due to structural failure.

**Internally Guyed Self-Supporting Towers** (Fig. 18-10): This structure satisfies conditions where external guy wires cannot be used. The internal guys act as structural members, increasing transverse strength with a considerable reduction in structural members.

**Self-Supporting Composite Towers** (Fig. 18-11): The self-supporting tower of conventional design can be built with steel base and aluminum top. This composite variation minimizes the cost premium. Like an all-aluminum tower, however, it requires no maintenance in the dangerous and high-cost vicinity of the conductors.

**Helicopters and Aluminum Towers:** The transmission line industry has developed ingenious and valuable short-cuts in its use of helicopters to transport and erect lightweight aluminum transmission towers and components.

This has been most dramatic in rough country, where tower installations virtually impossible by ordinary methods have been completed with relative ease by the versatile aircraft.

In all types of country, however, helicopters have proven highly economical, and aluminum tower crews are using them in many different operations.

Components of aluminum transmission towers—bundled or partly assembled—can be lifted, shifted or moved by helicopter. Use of ‘copters is especially helpful when running power lines through rough country. Towers assembled on pipe racks in marshaling areas reduce heavy equipment needs and dramatically increase productivity. Assembled towers can be carried by ‘copter from assembly points directly to tower sites and set, no matter how inaccessible the site might be.

Aluminum towers can be assembled on the ground at installation sites and then a helicopter can be used to tilt the towers easily and quickly to vertical positions.

When guyed-Y towers are being installed, a ‘copter can be used, first, to erect the vertical mast of the Y. The upper part of the Y can then be lifted by helicopter and attached with perfect alignment to the vertical mast.

Even the erection crews on tower jobs can be transported by helicopter—to and from the tower sites and from site to site—fast, efficiently in any terrain.

Aluminum Station Structures

Most of what has been presented above on the advantages of aluminum transmission line towers is directly applicable to aluminum supporting structures used in outdoor electrical substations. Despite a higher cost per unit weight, a comparable aluminum structure can often be completely erected at a cost equal to or somewhat less than steel. Thereafter the virtual elimination of maintenance costs for aluminum structures is an important bonus factor.

Station structures fully designed in aluminum will have the following economic and performance advantages:

**Light Weight:** The use of aluminum can mean a reduction in weight of up to 70% over a steel structure...a weight reduction without loss of structural integrity.

The weight advantage of aluminum can represent a major saving in erection costs. Aluminum allows a greater amount of sub-assembly prior to shipment and
construction site erection. More work can be done in the shop, thereby reducing the number of man hours in the field. Assembled sections that would be difficult to handle in steel are easily handled in aluminum. For example, where one man can lift an aluminum section, a similar steel section would require two or three men. The need for high cost heavy equipment also may be drastically reduced or often eliminated.

A further cost reduction is possible because aluminum's exceptionally high conductivity can simplify structural grounding and may eliminate a groundwire system.

Thus faster erection times and reduced labor, equipment and shipping costs are possible with aluminum.

Corrosion Resistance: The economy of aluminum's corrosion resistance should also be considered. Aluminum resists chemically corrosive atmospheres, salt air and industrial fumes and does not require protective coatings. And unlike steel that eventually rusts and requires painting, aluminum substations stay attractive without major maintenance.

The savings by not having to repaint the structure with attendant costly shutdowns may more than pay for the cost of the aluminum substation structure over a period of years.

Safety Factors: Safety is a very important advantage of aluminum substations. Since aluminum never requires painting, there is no need to run the risk of having painters climb or work in proximity to energized parts. Costly and inconvenient shutdowns in the interest of safety for painting purposes are unnecessary.

Appearance: Because of their excellent corrosion resistance and freedom from rust, aluminum substations remain modern looking year-in and year-out with a minimum of maintenance. Properly designed with the new, low silhouette, they offer improved appearance to metropolitan and suburban areas.

Fabrication. The relative ease of extruding aluminum makes it possible to offer special as well as standard structural shapes and sizes. This means aluminum can

---

Fig. 18-10. Pacific Gas & Electric Company 500 kV "internally" guyed structure in the test rack at Adelphon, Inc. Fort Worth, Texas.

Fig. 18-11. Aluminum top on steel body eliminates costly maintenance on 230 kV double circuit tower.
related structural applications of aluminum

Fig. 18-13. All-aluminum substation designed to operate at 750 kV.
be tailored to fit many different design requirements that utilize sizes, shapes, and lengths unobtainable with steel. As a result, a more efficient use can be made of the metal. Fig. 18-12 shows some of the structural shapes readily extruded.

In the field, when cutting and drilling operations are required, aluminum is a much easier metal to work with than steel, and it is easier to handle because of its light weight. Since there is no galvanizing, no special precautions are necessary to prevent corrosion after field cutting or drilling.

High Scrap Value: An important economic factor to consider is aluminum's recognized high scrap value. When a structure has fulfilled its useful life, aluminum will bring a much higher scrap return than other structural materials.

Aluminum Structural Alloys: The two most commonly used aluminum substation alloys are 6061-T6 and 6063-T6. Alloy 6061-T6 is a high strength metal used for tension and compression members. Alloy 6063-T6 has less strength and finds principal use in redundant structural members.

Tables 18-2 and 18-3 contain condensed but rather complete technical and availability information on the above two structural alloys.

Structural Design: Fabricators of aluminum structural components and assemblies maintain complete engineering design information which is available on request. Structural design handbooks for aluminum have been prepared and published by several manufacturers and by the Aluminum Association, and these may be obtained by writing to them.


Fastening Methods: Bolting—Where bolting is the desired method of fastening, 5/8” and 3/4” diameter bolts are recommended. Normally, aluminum bolts of high strength alloy 2024-T4, anodized and either chromate or nickel acetate sealed, are used with recessed nuts of alloy 6061-T6 lubricated with a wax coating to prevent galling. Recessed nuts preclude the need for washers. Aluminum coated steel bolts, aluminum lock bolts, and galvanized steel bolts may have applications under certain conditions. It is accepted practice to restrict bolts to one size in a given structure.

Riveting: In substation construction alloy 6061-T6 rivets are recommended because of their high shear value. They are available in sizes ranging up to 1” shank diameter. These rivets are cold driven as received.

To avoid corrosion, the rivet alloy selected should have equal or greater corrosion resistance than the alloys being joined. The rivet alloy should also be somewhat softer.

Rivets offer the advantage of an approximate 15% shear advantage over aluminum bolts. Additionally, shop riveted sub-assemblies eliminate deflections caused by bolt slippage.

Welding: All types of inert gas shielded arc welding (not requiring a flux) are acceptable for aluminum. However, two methods are most commonly used:

1. A tungsten electrode with the filler rod being fed by hand as in gas welding. (GTAW)
2. A consumable electrode of aluminum welding wire fed through the inert gas envelope. This is a fast method and is used also for automatic set-ups. (GMAW)

The strength of the weld generally varies from 60-90 percent of the original strength of the parent metal, depending on the alloy and temper. In many cases, proper arrangement of the seams may compensate for possible loss of strength. Butt seams offer the highest efficiency.
related structural applications of aluminum

### TABLE 18-2
Alloy 6061

Minimum Mechanical Properties—Values Are Given in Units of ksi (1000 lb/in²)

<table>
<thead>
<tr>
<th>Alloy and Temper</th>
<th>Product*</th>
<th>Thickness Range* in.</th>
<th>Tension</th>
<th>Compression</th>
<th>Shear</th>
<th>Bearing</th>
<th>Elasticity* E ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061-T6, T651</td>
<td>Sheet &amp; Plate</td>
<td>0.010-4.000</td>
<td>F&lt;sub&gt;tu&lt;/sub&gt; 42  F&lt;sub&gt;ty&lt;/sub&gt; 35</td>
<td>F&lt;sub&gt;c&lt;/sub&gt; 35</td>
<td>F&lt;sub&gt;bu&lt;/sub&gt; 27</td>
<td>F&lt;sub&gt;by&lt;/sub&gt; 20</td>
<td>88 58 10,100</td>
</tr>
<tr>
<td>-T6, T6510**</td>
<td>Extrusions</td>
<td>up thru 8.000</td>
<td>38 35</td>
<td>35 24 20</td>
<td>80 56 10,100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-T6, T651</td>
<td>Rolled Rod &amp; Bar</td>
<td>0.025-0.500</td>
<td>42 35</td>
<td>35 27 20</td>
<td>88 56 10,100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-T6</td>
<td>Drawn Tube</td>
<td>up thru 0.999</td>
<td>42 35</td>
<td>35 27 20</td>
<td>88 56 10,100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-T6</td>
<td>Pipe</td>
<td>over 0.999</td>
<td>38 35</td>
<td>35 24 20</td>
<td>80 56 10,100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-T6</td>
<td>Pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Most product and thickness ranges are taken from The Aluminum Association's "Aluminum Standards and Data."

† F<sub>tu</sub> and F<sub>ty</sub> are minimum specified values of ultimate (u) and yield (y) tensile (t) strengths. Other strength properties are corresponding minimum expected values.

‡ For deflection calculations an average modulus of elasticity is used; numerically this is 100 ksi lower than the values in this column.

** Values also apply to -T6511 temper.

### Typical Characteristics and Applications

#### ALLOY AND TEMPER

<table>
<thead>
<tr>
<th>RESISTANCE TO CORROSION General</th>
<th>Stress Corrosion Cracking</th>
<th>Workability (Cold)</th>
<th>Machineability°</th>
<th>Weldability*</th>
<th>TYPICAL APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>A</td>
<td>A</td>
<td>D</td>
<td>A</td>
<td>Heavy-Duty Structures Requiring Good Corrosion Resistance, Truck and Marine, Railroad Cars, Furniture, Pipelines</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

1. Ratings A through E are relative ratings in decreasing order of merit, based on exposures to sodium chloride solution by intermittent spraying or immersion. Alloys with A and B ratings can be used in industrial and seacoast atmospheres without protection. Alloys with C, D, and E ratings generally should be protected at least on faying surfaces.

2. Stress-corrosion cracking ratings are based on service experience and on laboratory tests of specimens exposed to the 3.5% sodium chloride alternate immersion test.

A = No known instance of failure in service or in laboratory tests.

B = No known instance of failure in service; limited failures in laboratory tests of short transverse specimens.

C = Service failures with sustained tension stress acting in short transverse direction relative to grain structure; limited failures in laboratory tests of long transverse specimens.

D = Limited service failures with sustained longitudinal or long transverse stress.

3. Ratings A through D for Workability (cold), and A through E for Machineability, are relative ratings in decreasing order of merit.

4. Ratings A through D for Weldability and Brazability are relative ratings defined as follows:

A = Generally weldable by all commercial procedures and methods.

B = Weldable with special techniques or for specific applications which justify preliminary trials or testing to develop welding procedure and weld performance.

C = Limited Weldability because of crack sensitivity or lack in resistance to corrosion and mechanical properties.

D = No commonly used welding methods have been developed.
**TABLE 18-3**  
**Alloy 6063**  
Minimum Mechanical Properties—Values Are Given in Units of ksi (1000 lb/in²)

<table>
<thead>
<tr>
<th>Alloy And Temper</th>
<th>Product*</th>
<th>Range Thickness</th>
<th>Tension</th>
<th>Compression</th>
<th>Shear</th>
<th>Bearing</th>
<th>Compressive Modulus of Elasticity‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>6063-T5</td>
<td>Extrusions</td>
<td>up thru 0.0500</td>
<td>22</td>
<td>16</td>
<td>16</td>
<td>13</td>
<td>46</td>
</tr>
<tr>
<td>-T5</td>
<td>Extrusions</td>
<td>over 0.500</td>
<td>21</td>
<td>15</td>
<td>15</td>
<td>12</td>
<td>44</td>
</tr>
<tr>
<td>-T6</td>
<td>Pipe</td>
<td>All</td>
<td>30</td>
<td>25</td>
<td>25</td>
<td>19</td>
<td>63</td>
</tr>
</tbody>
</table>

* Most product and thickness ranges are taken from The Aluminum Association’s “Aluminum Standards and Data.”
† *F₂₅ and *F₁₅ are minimum specified values, other strength properties are corresponding minimum expected values.
‡ For deflection calculations an average modulus of elasticity is used; numerically this is 100 ksi lower than the values in this column.

**Typical Characteristics and Applications**

<table>
<thead>
<tr>
<th>ALLOY AND TEMPER</th>
<th>RESISTANCE TO CORROSION</th>
<th>WELDABILITY*</th>
<th>TYPICAL APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stress-Corrosion Cracking</td>
<td>Workability (Cold)</td>
<td>Arc</td>
</tr>
<tr>
<td>6063-T1</td>
<td>A</td>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>T4</td>
<td>A</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>T5, T52</td>
<td>A</td>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>T6</td>
<td>A</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>T83, T831, T832</td>
<td>A</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

See footnotes below Table 18-2 on page 18-11.