Phil. Data - Aluminum

# GENERAL INFORMATION

Commercially pure aluminum has a tensile strength of about 13,000 pounds per square inch. Its usefulness as a structural material in this form, thus, is somewhat limited. By working the metal, as by cold rolling, its strength can be approximately doubled. Much larger increases in strength can be obtained by alloying aluminum with small percentages of one or more other metals such as manganese, silicon, copper, magnesium or zinc. Like pure aluminum, the alloys are also made stronger by cold working. Some of the alloys are further strengthened and hardened by heat treatments, so that, today, aluminum alloys having tensile strengths approaching 80,000 pounds per square inch are available.

A wide variety of mechanical characteristics, or tempers, is available in aluminum alloys through various combinations of cold work and heat treatment. In specifying the temper for any given product, the fabricating process and the amount of cold work to which it will subject the metal should be kept in mind. In other words, the temper specified should be such that the amount of cold work the metal will receive during fabrication will develop the desired characteristics in the finished products.

# ALLOY AND TEMPER DESIGNATIONS FOR WROUGHT ALUMINUM

## WROUGHT ALUMINUM AND ALUMINUM ALLOY DESIGNATION SYSTEM

A system of four-digit numerical designations is used to identify wrought aluminum and wrought aluminum alloys. The first digit indicates the alloy group as shown in Table 1: The 1xxx series is for minimum aluminum purities of 99.00 percent and greater, and the 2xxx through 8xxx series group aluminum alloys by major alloying elements. The last two digits identify the aluminum alloy or indicate the aluminum purity. The second digit indicates modifications of the original alloy or impurity limits.

## ALUMINUM

In the 1xxx group for minimum aluminum purities of 99.00 percent and greater, the last two of the four digits in the designation indicate the minimum aluminum percentage. These digits are the same as the two digits to the right of the decimal point in the minimum aluminum percentage when it is expressed to the nearest 0.01 percent. The second digit in the designation indicates modifications in impurity limits. If the second digit in the designation is

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zero, it indicates that there is no special control on individual impurities; integers 1 through 9, which are assigned consecutively as needed, indicate a special control of one, or more, individual impurities.

## ALUMINUM ALLOYS

In the 2xxx through 8xxx alloy groups, the last two of the four digits in the designation have no special significance; they serve only to identify the different aluminum alloys in the group. The second digit in the alloy designation indicates alloys modifications. If the second digit in the designation is zero, it indicates the original alloy; integers 1 through 9, which are assigned consecutively, indicate alloy modifications.

## EXPERIMENTAL ALLOYS

Experimental alloys are also designated in accordance with this system, but they are indicated by the prefix X. The prefix is dropped when the alloy is no longer experimental. During development and before they are designated as experimental, new alloys are identified by serial numbers assigned by their originators. Use of the serial number is discontinued when the X number is assigned.

### TABLE 1 — Designations for Wrought Alloy Groups

| | | Alloy No. |
|---|---|---|
| Aluminum—99.00% minimum and greater | | 1xxx |
| | Major Alloying Element | |
| Aluminum Alloys grouped by Major Alloying Elements | Copper | 2xxx |
| | Manganese | 3xxx |
| | Silicon | 4xxx |
| | Magnesium | 5xxx |
| | Magnesium and Silicon | 6xxx |
| | Zinc | 7xxx |
| | Other Element | 8xxx |
| Unused Series | | 9xxx |

## TEMPER DESIGNATIONS FOR ALUMINUM ALLOYS, CAST AND WROUGHT

The temper designation system is used for all forms of wrought and cast aluminum and aluminum alloys—except ingot. It is based on the sequences of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, the two being separated by a hyphen. Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one, or more, digits following the letter. These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.

## BASIC TEMPER DESIGNATIONS

**F as fabricated.** Applies to the products of shaping processes in which no special control over thermal conditions or strain-hardening is employed. For wrought products, there are no mechanical property limits.

**O annealed (wrought products only).** Applies to wrought products, which are fully annealed to obtain the lowest strength condition.

**H strain-hardened (wrought products only).** Applies to products which have their strength increased by strain-hardening, with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two, or more, digits.

**W solution heat-treated.** An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is indicated; for example, W 1/2 hr.

**T thermally treated to produce stable tempers other than F, O or H.** Applies to products which are thermally treated, with or without supplementary strain-hardening, to produce stable tempers. The T is always followed by one or more digits.

## SUBDIVISIONS OF H TEMPER: STRAIN-HARDENED

The first digit following the H indicates the specific combination of basic operations, as follows:

**H1 strain-hardened only.** Applies to products which are strain-hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.

**H2 strain-hardened and partially annealed.** Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H1 tempers and slightly higher elongation. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.

**H3 strain-hardened and stabilized.** Applies to products which are strain-hardened and whose mechanical properties are stabilized by a low-temperature thermal treatment, which results in slightly lowered tensile strength and improved ductility. This designation is applicable only to those alloys which, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening before the stabilization treatment.

## SUBDIVISIONS OF THE -H1, -H2, -H3 TEMPERS

The digit following the designations H1, H2, and H3 indicates the degree of strain-hardening. Numeral 8 has been assigned to indicate tempers having an ultimate tensile strength equivalent to that achieved by a cold reduction. Tempers between 0 (annealed) and 8 are designated by numerals 1 through 7.

Material having an ultimate tensile strength about midway between that of the 0 temper and that of the 8 temper is designated by the numeral 4; about midway between the 0 and 4 tempers by the numeral 2; and about midway between the 4 and 8 tempers by the numeral 6. Numeral 9 designates tempers whose minimum ultimate tensile strength exceeds that of the 8 temper by 2.0 ksi or more. For two-digit H tempers whose second digit is odd, the standard limits for ultimate tensile strength are exactly midway between those of the adjacent two-digit H tempers whose second digits are even.

The third digit, when used, indicates a variation of a two-digit temper. It is used when the degree of control of temper or the mechanical properties are different from but close to those for the two-digit H temper designation to which it is added, or when some other characteristic is significantly affected. (See Appendix for three-digit H tempers.)

Note: The minimum ultimate tensile strength of a three-digit H temper is at least as close to that of the corresponding two-digit H temper as it is to the adjacent two-digit H tempers.

The following three-digit H temper designations have been assigned for wrought products in all alloys:

**H_11** Applies to products that incur sufficient strain hardening after the final anneal that they fail to qualify as annealed but not so much or so consistant an amount of strain hardening that they qualify as H_1.

**H112** Applies to products that may acquire some temper from working at an elevated temperature and for which there are mechanical property limits.

The following three-digit H temper designations have been assigned for:

| patterned or embossed sheet | fabricated from |
|---|---|
| H114 | 0 temper |
| H124, H224, H324 | H11, H21, H31 temper, respectively |
| H134, H234, H334 | H12, H22, H32 temper, respectively |
| H144, H244, H344 | H13, H23, H33 temper, respectively |
| H154, H254, H354 | H14, H24, H34 temper, respectively |
| H164, H264, H364 | H15, H25, H35 temper, respectively |
| H174, H274, H374 | H16, H26, H36 temper, respectively |
| H184, H284, H384 | H17, H27, H37 temper, respectively |
| H194, H294, H394 | H18, H28, H38 temper, respectively |
| H195, H295, H395 | H19, H29, H39 temper, respectively |

## SUBDIVISIONS OF THE T TEMPER

Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows:

**T1 cooled from an elevated-temperature shaping process and naturally aged to a substantially stable condition.** Applies to products for which the rate of cooling from an elevated-temperature shaping process, such as casting or extrusion, is such that their strength is increased by room-temperature aging.

**T2 annealed (cast products only).** Applies to cast products which are annealed to improve ductility and dimensional stability.

**T3 solution heat-treated and then cold-worked.** Applies to products which are cold-worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

**T4 solution heat-treated and naturally aged to a substantially stable condition.** Applies to products which are not cold-worked after solution heat-treatment, or in which the effect of cold work is flattening or straightening may not be recognized in mechanical property limits.

**T5 cooled from an elevated-temperature shaping process and then artificially aged.** Applies to products which are cooled from an elevated-temperature shaping process, such as casting or extrusion, and then artificially aged to improve mechanical properties or dimensional stability, or both.

**T6 solution heat-treated and then artificially aged.** Applies to products which are not cold-worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

**T7 solution heat-treated and then stabilized.** Applies to products which are stabilized to carry them beyond the point of maximum strength to provide control of some special characteristics.

**T8 solution heat-treated, cold-worked, and then artificially aged.** Applies to products which are cold-worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

**T9 solution heat-treated, artificially aged, and then cold worked.** Applies to products which are cold-worked to improve strength.

**T10 cooled from an elevated-temperature shaping process, artificially aged and then cold-worked.** Applies to products which are artificially aged after cooling from an elevated-temperature shaping process, such as casting or extrusion, and then cold worked to further improve strength.

Additional digits, the first of which shall not be zero, may be added to designations T1 through T10 to indicate a variation in treatment, which significantly alters the characteristics of a product.

The following specific additional digits have been assigned for stress-relieved tempers of wrought products:

**T_51 stress relieved by stretching.** Applies to the following products when stretched the indicated amounts after solution heat-treatment or cooling from an elevated temperature shaping process.

| | |
|---|---|
| Plate . . . . . . . . . . . . . . . . . . . . . . | 1 1/2 to 3% permanent set |
| Rod, bar, shapes, extruded tube. | 1 to 3% permanent set |
| Drawn tube . . . . . . . . . . . . . . . . | 1/2 to 3% permanent set |

Applies directly to plate and rolled or cold-finished rod and bar. These products receive no further straightening after stretching.

Applies to extruded rod, bar, shapes and tube and to drawn tube when designated as follows:

> **T_510** Products that receive no further straightening after stretching.
>
> **T_511** Products that may receive minor straightening after stretching to comply with standard tolerances.

**T_52 stress-relieved by compressing.** Applies to products which are stress-relieved by compressing after solution heat-treatment, or by cooling from an elevated-temperature shaping process to produce a permanent set of 1 to 5 percent.

**T_54 stress-relieved by combined stretching and compressing.** Applies to die forgings which are stress relieved by restriking cold in the finish die.

The following temper designations have been assigned for wrought products heat-treated from O or F temper to demonstrate response to heat-treatment.

**T42** Solution heat-treated from the O or F temper to demonstrate response to heat-treatment, and naturally aged to a substantially stable condition.

**T62** Solution heat-treated from the O or F temper to demonstrate response to heat-treatment, and artificially aged.

Temper designations T42 and T62 may also be applied to wrought products heat-treated from any temper by the user when such heat-treatment results in the mechanical properties applicable to these tempers.

## GENERAL INFORMATION ON ALUMINUM ALLOYS

In high-purity form, aluminum is soft and ductile. Most commercial uses, however, require greater strength than pure aluminum affords. This is achieved in aluminum first by the addition of other elements to produce various alloys, which singly, or in combination, impart strength to the metal. Further strengthening is possible by means which classify the alloys roughly into two categories—non-heat-treatable and heat-treatable.

**non-heat-treatable-alloys**—The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium—singly or in various combinations. The non-heat-treatable alloys are usually designated, therefore, in the 1000, 3000, 4000 or 5000 series. Since these alloys are work-hardenable, further strengthening is made possible by various degrees of cold working, denoted by the "H" series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated-temperature treatment called stabilizing to insure stability of properties.

**heat-treatable alloys**—The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc and silicon. Since these elements singly, or in various combinations, show increasing solid solubility in aluminum with increasing temperature, it is possible to subject them to thermal treatments which will impart pronounced strengthening.

The first step, called heat treatment or solution heat treatment, is an elevated temperature process designed to put the soluble element or elements in solid solution. This is followed by rapid quenching, usually in water, which momentarily "freezes" the structure and, for a short time, renders the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at below-freezing temperatures until they are ready to form them. At room or elevated temperatures, the alloys are not stable after quenching, however, and precipitation of the constituents from the super-saturated solution begins. After a period of several days at room temperature, termed aging or room-temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature; but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age-harden for long periods of time at room temperature.

By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening. By the proper combination of solution heat treatment, quenching, cold-working and artificial aging, the highest strengths are obtained.

**clad alloys**—The heat-treatable alloys in which copper or zinc are major alloying constituents, are less resistant to corrosive attack than the majority of non-heat-treatable alloys. To increase the corrosion resistance of these alloys in sheet and plate form, they are often clad with high-purity aluminum, a low magnesium-silicon alloy, or an alloy

containing 1 percent zinc. The cladding, usually from 2 1/2 to 5 percent of the total thickness on each side, not only protects the composite due to its own inherently excellent corrosion resistance, but also exerts a galvanic effect, which further protects the core material.

Special composites may be obtained, such as clad non-heat-treatable alloys for extra corrosion protection, for brazing purposes, or for special surface finishes. Some alloys in wire and tubular form are clad for similar reasons, and, on an experimental basis, extrusions also have been clad.

**annealing characteristics**—All wrought aluminum alloys are available in annealed form. In addition, it may be desirable to anneal an alloy from any other initial temper—after working or between successive stages of working, such as in deep drawing.

## EFFECT OF ALLOYING ELEMENTS

**1000 series**—Aluminum of 99 percent or higher purity has many applications, especially in the electrical and chemical fields. These alloys are characterized by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties and excellent workability. Moderate increases in strength may be obtained by strain-hardening. Iron and silicon are the major impurities.

**2000 series**—Copper is the principal alloying element in this group. These alloys require solution heat-treatment to obtain optimum properties; in the heat-treated condition, mechanical properties are similar to, and sometimes exceed, those of mild steel. In some instances, artificial aging is employed to further increase the mechanical properties. This treatment materially increases yield strength, with attendant loss in elongation; its effect on tensile (ultimate) strength is not as great. The alloys in the 2000 series do not have as good corrosion resistance as most other aluminum alloys and, under certain conditions, they may be subject to intergranular corrosion. Therefore, these alloys in the form of sheet are usually clad with a high-purity alloy or a magnesium-silicon alloy of the 6000 series, which provides galvanic protection to the core material and, thus, greatly increases resistance to corrosion. Alloy 2024 is perhaps the best known and most widely used aircraft alloy.

**3000 series**—Manganese is the major alloying element of alloys in this group, which are generally non-heat-treatable. Because only a limited percentage of manganese, up to about 1.5 percent, can be effectively added to aluminum, it is used as a major element in only a few instances. One of these, however, is the popular 3003, which is widely used as a general-purpose alloy for moderate-strength applications requiring good workability.

**4000 series**—Major alloying element of this group is silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons, aluminum-silicon alloys are used in welding wire and as brazing alloys, where a lower melting point than that of the parent metal is required. Most alloys in this series are non-heat-treatable, but when used in welding heat-treatable alloys, they will pick up some of the alloying constituents of the latter and, so, respond to heat treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark gray when anodic oxide finishes are applied, and, hence, are in demand for architectural applications.

**5000 series**—Magnesium is one of the most effective and widely used alloying elements for aluminum. When it is used as the major alloying element or with manganese, the result is a moderate- to high-strength non-heat-treatable alloy. Magnesium is considerable more effective than manganese as a hardener—about 0.8 percent magnesium being equal to 1.25 percent manganese, and it can be added in considerably higher quantities. Alloys in this series possess good welding characteristics and good resistance to corrosion in a marine atmosphere. However, certain limitations should be placed on the amount of cold work and the safe operating temperatures permissible for the higher magnesium content alloys (over about 3 1/2 percent for operating temperatures above about 150° F [66° C]) to avoid susceptibility to stress corrosion.

**6000 series**—Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicide, thus making them heat-treatable. Major alloy in this series is 6061, one of the most versatile of the heat-treatable alloys. Though less strong than most of the 2000 or 7000 alloys, the magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength. Alloys in this heat-treatable group may be formed in the T4 temper (solution heat-treated, but not artificially aged) and then reach full T6 properties by artificial aging.

**7000 series**—Zinc is the major alloying element in this group, and when coupled with a smaller percentage of magnesium results in heat-treatable alloys of very high strength. Usually, other elements such as copper and chromium are also added in small quantities. An outstanding member of this group is 7075, which is among the highest strength alloys available and is used in air-frame structures and for highly stressed parts.