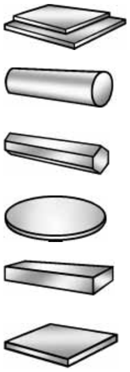
More About Aluminum and Aluminum Alloys



To help identify aluminum and aluminum alloys, the Aluminum Association created a system of four-digit numbers. The first number in the four-digit number indicates the alloy group.

Alloy Numbering Designation	Major Alloying Element
1XXX	Pure Aluminum (99% and Greater)
2XXX	Copper
3XXX	Manganese
4XXX	Silicon
5XXX	Magnesium
6XXX	Magnesium and Silicon
7XXX	Zinc

Copper—One of the most important additions to aluminum. It has significant solubility and a substantial strengthening effect through the age-hardening characteristics it imparts to aluminum.

Manganese—An addition that provides substantial strength.

Silicon—In addition to lowering the melting point and increasing the fluidity of aluminum, silicon adds moderate strength.

Magnesium—One of the most effective and widely used alloying elements, magnesium adds substantial strength and improves the work-hardening characteristics of aluminum. When combined with other elements such as copper and zinc, it adds even greater strength.

Zinc—Used with magnesium, zinc helps produce the highest-strength, heat-treatable aluminum alloys.

Nonheat-Treatable vs. Heat-Treatable Alloys

Nonheat-Treatable Alloys—The initial strength of nonheat-treatable alloys depends on the hardening effects of elements (individually or in various combinations) such as manganese, magnesium, silicon, and iron. You can't harden these alloys by heat treating—they can only be strengthened by strain hardening or cold working.

Nonheat-treatable alloys include alloys with the following numbering designation: **1**XXX, **3**XXX, and **5**XXX.

Heat-Treatable Alloys—The initial strength of heat-treatable alloys is heightened by adding elements (individually or in various combinations) such as copper, silicon, magnesium, and zinc. You can further strengthen these alloys by performing a suitable thermal treatment and/or cold working.

Heat-treatable alloys include alloys with the following numbering designation: **2**XXX, **6**XXX, and **7**XXX.

Temper Designations

Temper designations (for example: O, H14, and T4) consist of a letter that may or may not be followed by one or more numbers that indicate operations that have taken place at the mill. There are five basic temper designations:

F As Fabricated − No controlled strain hardening or thermal treatment operations have taken place. There are no specified mechanical properties and strength levels may vary greatly.

O Annealed − Material has undergone an annealing treatment at approximately 600° F to reduce strength and hardness levels. Also known as dead soft.

W Solution Heat Treated − An unstable temper for some heat-treatable alloys that spontaneously age harden at room temperature after heat treating.

H Strain Hardened − Material has been strain hardened or cold worked for added strength. The "H" is always followed by two or more digits.

The first digit after the "H" indicates the following:

H1 Strain Hardened Only
Material has had no additional thermal treatment after strain hardening or cold working.

H2 Strain Hardened and Partially Annealed
Material has been thermally treated to reduce strength to the desired level by partial annealing.

H3 Strain Hardened and Stabilized
This operation prevents age softening at room temperature after strain hardening.

The second digit after the "H" indicates the degree of strain hardening that has occurred:

1 ⅛ Hard
2 ¼ Hard
3 ⅜ Hard
4 ½ Hard
5 ⅝ Hard
6 ¾ Hard
7 ⅞ Hard
8 Full Hard
9 Extra Hard

Using the above information, you can determine that a material with a temper of H14 has been strain hardened to a ½ Hard level.

T Thermally Treated − Material has been thermally treated for added strength. The "T" is always followed by one or more digits.

The first digit after the "T" indicates the following:

T1 Cooled from an elevated temperature and naturally aged.
T2 Cooled from an elevated temperature, cold worked, and naturally aged.
T3 Solution heat treated, cold worked, and naturally aged.
T4 Solution heat treated and naturally aged.
T5 Cooled from an elevated temperature and artificially aged.
T6 Solution heat treated and artificially aged.
T7 Solution heat treated and over aged/stabilized.
T73 Solution heat treated, artificially aged, and artificially over aged.
T8 Solution heat treated, cold worked, and artificially aged.
T9 Solution heat treated, artificially aged, and cold worked.
T10 Cooled from an elevated temperature, cold worked, and artificially aged.

The following additional digits may be added to indicate stress relieving:

51 Stress relieved by stretching with no subsequent straightening.
510 Extruded products and drawn tube stress relieved by stretching with no subsequent straightening.
511 Extruded products and drawn tube stress relieved by stretching with permissible minor straightening.
52 Stress relieved by compressing.

Using the above information, you can determine that a material with a temper of T6511 has been solution treated, artificially aged, and stress relieved by stretching with permissible minor straightening.

Alloy 1100

Heat Treatment: This alloy cannot be hardened by heat treating. It can only be hardened by cold working (strain hardening).

To produce the annealed condition (O temper), heat to 650° F long enough to allow thorough heating and then air cool (cooling rate is not important). *Note:* Annealing may be necessary after severe cold working.

Workability: This alloy can be hot or cold rolled without difficulty. It can also be readily drawn, spun, stamped, or forged.

Starting with metal in the annealed temper, parts requiring successive drawing and spinning can be made without intermediate annealing. After extensive cold work, however, reannealing may be necessary before further cold work can be performed.

Alloy 2011

Heat Treatment: *O Temper (Annealing)*—To anneal material in the heat-treated condition, heat to 775° F, hold temperature for two to three hours, cool at a rate of 50° F per hour down to 500° F, then air cool.

T4 Temper (Solution Heat Treating)—Heat to 975° F, hold temperature for several hours, then quench in water.

T3 Temper—Solution heat treat to T4 temper and cold work.

T8 Temper—Solution heat treat, cold work, heat treat to 320° F for 12 to 16 hours to age, and finally cool at any desired rate.

Workability: This alloy can be readily hot worked at temperatures from 500° to 900° F. Its cold workability is good in the T4 and T451 tempers; fair in the T3 temper; and poor in the T8 temper.

Alloy 2017

Heat Treatment: *O Temper (Annealing)*—To remove the effect of a previous heat treatment, heat to 775° F, hold temperature for two to three hours, cool at a rate of 50° F per hour down to 500° F, then air cool. To remove the effects of cold work, heat to 640° to 660° F, hold temperature for two hours, and then air cool.

T4 Temper (Solution Heat Treating)—Heat to 930° to 950° F, hold temperature for one to four hours, quench in cold water, and then age at room temperature.

Workability: This alloy has good formability. Cold working (shaping, bending, etc.) can be readily accomplished by conventional means. Cold working is easiest when the alloy is in the T4 temper.

Alloy 2024

Heat Treatment: *O Temper (Annealing)*—To soften the alloy from a heat-treated condition, heat to 750° to 800° F, hold temperature for two hours, then cool in furnace. To anneal the alloy after cold working, heat to 640° to 660° F, hold temperature for two hours, and then air cool.

T3 Temper—Solution heat treat to T4 temper and then cold work to straighten or flatten (approximately ½ to 3% cold work).

T4 Temper (Solution Heat Treating)—Heat to 920° F, quench in cold water, and then age at room temperature.

T6 Temper (Solution Heat Treating plus Aging)—Heat to 920° F, quench in cold water, reheat to age at 365° to 385° F for 9 to 12 hours, and then air cool.

T81 Temper (T3 plus Aging)—Solution heat treat to 920° F, quench in cold water, flatten (about 1% cold work), reheat to age at 365° to 385° F for 9 to 12 hours, and then air cool.

Workability: This alloy should not be hot formed because it will effect corrosion resistance. If, for example, T4 temper is hot worked, it is necessary to age the material to a T6 temper to restore the corrosion resistance.

Alloy 3003

Heat Treatment: This alloy cannot be hardened by heat treating. It can only be hardened by cold working (strain hardening).

To anneal (O Temper), during or following cold working, heat to 775° F, hold temperature long enough to thoroughly heat, and then air cool.

Workability: This alloy can be readily hot and cold worked. Hot working temperature range is 500° to 950° F.

Alloy 4032

Heat Treatment: *O Temper (Annealing)*—Heat to 750° to 800° F, cool at a rate of 50° F per hour down to 500° F, and then air cool.

T4 Temper (Solution Heat Treating)—Heat to 940° to 960° F for ½ to 12 hours (depending on section thickness) and then quench in cold water.

T6 Temper (Solution Heat Treating plus Aging)—Heat to 940° to 960° F for ½ to 12 hours (depending on section thickness), quench in cold water, reheat to 335° to 345° F for 8 to 12 hours, and then air cool.

Workability: This alloy is typically hot worked, not cold worked. Hot working temperature range is 700° to 950° F.

Alloy 5052

Heat Treatment: This alloy cannot be hardened by heat treating. It can only be cold worked (strain hardening).

O Temper (Annealing)—Heat to 650° F, hold temperature long enough to thoroughly heat, then air cool.

Workability: This alloy is ideal for cold working and may be formed by drawing or spinning. It may, however, require intermediate annealing because of its relatively rapid rate of strain hardening. The hot working temperature range is 500° to 950° F.

Alloy 6013

Heat Treatment: *O Temper (Annealing)*—Heat to 775° F, hold temperature for two to three hours, cool at a rate of 50° F per hour down to 500° F, then air cool.

W Temper (Solution Heat Treating)—Heat to 1050° to 1060° F, hold temperature for 20 to 30 minutes, then quench in cold water.

T4 Temper (Solution Heat Treating plus Natural Aging)—Solution heat treat to W temper (see above) then naturally age (room temperature) to form a stable T4 temper in two weeks.

T6 Temper (Solution Heat Treating plus Accelerated Aging)—Solution heat treat to W temper (see above), age at 375° F for four hours, and then air cool.

Post-Weld Heat Treatment—Heat at 1000° F for 20 to 30 minutes and then quench in water.

Workability: This alloy has good cold-forming qualities. Difficult cold-forming operations, however, may require intermediate anneals . . . in which case, re-solution heat treating and T6 temper aging should be performed.

Alloy 6061

Heat Treatment: *O Temper (Annealing)*—Heat to 775° F, hold temperature for two to three hours, cool at a rate of 50° F per hour down to 500° F, then air cool.

T4 Temper (Solution Heat Treating)—Heat to 985° F, hold temperature long enough for thorough heating, then quench in water.

T451 Temper—Stress relieve (by stretching) to produce a specified amount of permanent set subsequent to solution heat treating and prior to precipitation heat treating.

T6 Temper (Precipitation Heat Treating)—Heat to 320° F, hold temperature for 18 hours, and then air cool. You can also heat to 350° F, hold temperature for 8 hours, and then air cool.

T651 Temper—Stress relieve (by stretching) to produce a specified amount of permanent set subsequent to solution heat treating and prior to precipitation heat treating.

Workability: In the annealed condition, this alloy can be readily cold worked by conventional methods such as bending, forming, deep drawing, spinning, and stamping. Hot working temperature range is 500° to 700° F.

Alloy 6063

Heat Treatment: *O Temper (Annealing)*—Heat to 775° F, hold temperature for three hours, cool at a rate of 50° F per hour down to 500° F, and then air cool. *T4 Temper (Solution Heat Treating)*—Heat to 970° F, hold temperature for one hour, and then quench in water.

T6 Temper (Solution Heat Treating plus Aging)—Age T4 material by reheating to 350° F, hold temperature for six to eight hours, and then cool at any desired rate.

Workability: Cold-working characteristics are good for all conventional forming methods. The most severe cold-forming operations should be performed in the O temper state and then the material should be heat treated and aged. For operations that can't be completed in the fully aged (T6) state, and where a high degree of workability of annealed material is not required, T4 temper is recommended. Hot working temperature range is 500° to 950° F.

Alloy 6262

Heat Treatment: *O Temper (Annealing)*—Solution anneal at 1000° F, hold temperature long enough for thorough heating, and then quench in hot water.

T4 and T42 Tempers (Solution Heat Treating plus Natural Aging)—After solution annealing, allow material to naturally age at room temperature.

T6 and T62 Tempers (Solution Heat Treating plus Accelerated Aging)—After solution annealing, age as follows depending on the product form: for cold-formed bar or rod, age at 340° F for eight hours; for extruded shapes, age at 350° F for 12 hours.

Workability: Cold-working characteristics are fair for the following tempers: T6, T651, T6510, and T6511. Cold-working characteristics are poor for T9 temper.

Alloy 7075

Heat Treatment: *O Temper (Annealing)*—Heat to 775° F, hold temperature for two to three hours, cool at a rate of 50° F per hour down to 500° F, then air cool.

W Temper (Solution Heat Treating)—For sheet and plate, heat to 900° F, hold temperature for two hours, and then quench in water. For rolled rod, heat at 915° F and then quench in water. For extruded stock, forgings, and drawn tube, heat at 870° to 880° F, hold temperature for two hours, and then quench in water

T6 and T651 Tempers (Precipitation Heat Treating)—Heat to 250° F, hold temperature for 24 hours, and then air cool.

T73 and T7351 Tempers (Precipitation Heat Treating)—Heat to 225° F and hold temperature for six to eight hours. Then, heat to 325° F and hold for 24 to 30 hours for sheet and plate, or heat to 350° F and hold for 8 to 10 hours for rolled rod and bar, or heat to 350° F and hold for 6 to 8 hours for extrusions.

Workability: This alloy is readily cold worked in the soft, annealed condition. Conventional forming methods may be used but, because of its strength, you must make greater allowances for springback. To increase formability, warm material to 250° F during forming in the annealed temper. Since formability decreases with time due to age hardening, it's best to form in the freshly quenched condition.

Physical and Mechanical Properties of Aluminum Alloys

Note: The following properties are not guaranteed, since in most cases they are average for various sizes, forms, and manufacturing methods and may not exactly represent any particular material or size. ***This data is not meant for design purposes, but is intended only as a basis for comparisons.***

Alloy	Temper	Ultimate Tensile Strength, ksi	Yield Strength, ksi	Elongation % in 2″	Brinell Hardness	Shear Strength, ksi	Melting Range, °F	Thermal Conductivity @ 77° F (BTU/ft.^{2}/in./hr.)	Electrical Conductivity @ 68° F (% of Intl. Annealed Copper Standard)	Electrical Resistivity @ 68° F (Ohm−Cir. Mil/ft.)	Nominal Density (lbs./cu. in.)
1100	O Annealed H14 H18	13 18 24	5 17 22	35 9 5	23 32 44	9 11 13	1190-1215 1190-1215 1190-1215	1540 1510 1510	59 57 57	18 18 18	0.098 0.098 0.098
2011	T3	55	43	n/a	95	32	1005-1190	1050	39	27	0.102
2017	O Annealed T4, T451	26 62	10 40	n/a n/a	45 105	18 38	955-1185 955-1185	1340 930	50 34	21 31	0.101 0.101
2024	O Annealed T3 T4, T351	27 70 68	11 50 47	20 18 20	47 120 120	18 41 41	935-1180 935-1180 935-1180	1340 840 840	50 30 30	21 35 35	0.1 0.1 0.1
3003	O Annealed H14 H18	16 22 29	6 21 27	30 8 4	28 40 55	11 14 16	1190-1210 1190-1210 1190-1210	1340 1100 1070	50 41 40	21 25 26	0.099 0.099 0.099
4032	T6	55	46	n/a	120	38	990-1060	960	35	30	0.097
5052	O Annealed H32 H38	28 33 42	13 28 37	25 12 7	47 60 77	18 20 24	1125-1200 1125-1200 1125-1200	960 960 960	35 35 35	30 30 30	0.097 0.097 0.097
6013	T8	65	62	11	130	36	1052-1195	1140	38	n/a	0.098
6020	T8	44	42	15	100	n/a	n/a	1190	46	n/a	0.098
6061	O Annealed T6, T651	18 45	8 40	25 12	30 95	12 30	1080-1205 1080-1205	1250 1160	47 43	22 24	0.098 0.098
6063	O Annealed T5 T83	13 27 37	7 21 35	n/a 12 9	25 60 82	10 17 22	1140-1210 1140-1210 1140-1210	1510 1450 1390	58 55 53	18 19 20	0.097 0.097 0.097
6262	T9	58	55	n/a	120	35	1080-1205	1190	44	24	0.098
7068	T6511	103	99	9	190	53	890-1175	n/a	30	n/a	0.103
7075	O Annealed T6, T651	33 83	15 73	17 11	60 150	22 48	n/a 890-1175	n/a 900	n/a 33	n/a 31	0.101 0.101

The chart above shows the properties of several alloys in the annealed, ½ hard, and full hard tempers. Note that the alloys can be substantially strain-hardened to produce even greater strengths. While strain-hardening increases both tensile and yield strengths, the effect is more pronounced for yield strength. That is, yield strength approaches the tensile strength and they are nearly equal in the full hard temper.