

Non-Ferrous Metals

Introduction

Non-ferrous metals are metals that do not contain iron. There are two groups of metals; ferrous and non-ferrous. Ferrous metals contain iron, for example carbon steel, stainless steel (both alloys; mixtures of metals) and wrought iron. Non-ferrous metals don't contain iron, for example aluminium, brass, copper (which can be remembered as ABC) and titanium. You can also get non-ferrous metals as alloys eg, brass is an alloy of copper and zinc.

Nonferrous metals are specified for structural applications requiring reduced weight, higher strength, nonmagnetic properties, higher melting points, or resistance to chemical and atmospheric corrosion. They are also specified for electrical and electronic applications.

Non-Ferrous Metals include:

1. **Aluminum**
2. **Beryllium**
3. **Copper**
4. **Lead**
5. **Magnesium**
6. **Nickel**
7. **Precious Metals**
8. **Refractory Metals**
9. **Tin**
10. **Titanium**
11. **Zinc**
12. **Zirconium**

1. Aluminum

Pure aluminum is a silvery-white metal with many desirable characteristics. It is light, nontoxic (as the metal), nonmagnetic and nonsparking. It is easily formed, machined, and cast. Pure aluminum is soft and lacks strength, but alloys with small amounts of copper, magnesium, silicon, manganese, and other elements have very useful properties. Aluminum is an abundant element in the earth's crust, but it is not found free in nature. The Bayer process is used to refine aluminum from bauxite, an aluminum ore. Because of aluminum's mechanical and physical properties, it is an extremely convenient and widely used metal.

Some Common Uses -

Building & Construction Industry:

- door and window frames
- wall cladding, roofing, awnings

Manufacture of Electrical Products:

- high tension power lines, wires, cables, busbars
- components for television, radios, refrigerators and air-conditioners

Packaging & Containers:

- beverage cans, bottle tops
- foil wrap, foil semi-rigid containers

Cooking Utensils:

- kettles and saucepans

Aeronautical, Aviation & Automotive Industries:

- propellers
- airplane and vehicle body sheet
- gearboxes, motor parts

Leisure Goods:

- tennis racquets, softball bats
- indoor and outdoor furniture

Properties -

- very lightweight (about 1/3 the mass of an equivalent volume of steel or copper) but with alloying can become very strong.
- excellent thermal conductor
- excellent electrical conductor (on a weight-for-mass basis, aluminium will conduct more than twice as much electricity as copper)
- highly reflective to radiant energy in the electromagnetic spectrum
- highly corrosion resistant in air and water (including sea water)
- highly workable and can be formed into almost any structural shape
- non-magnetic
- non-toxic

PROPERTIES OF ALUMINUM DIE CASTING ALLOYS						
	AA NUMBER					
	A360.0	A380.0	383	A413.0	B390.0	384
Ultimate Tensile Strength (ksi)	46	47	45	42	40.5	48
Tensile Yield Strength (ksi)	24	23	22	19	35	24
Elongation (% in 2" G.L.)	3.5	3.5	3.5	3.5		1.0 2.5
Hardness (HB)	75	80	80	120	85	
Shear Strength (ksi)	26	27	25	29		
Charpy Impact Strength (ft. lb.—unnotched)	4.2	3.5		2		
Fatigue Strength (ksi) (limit @ 500 million cycles)	18	20	19	20		20
Density (lb./in.³)	0.095	0.098	0.097	0.096	0.099	0.098
Melting Range(°F) approx.	1035-1105	1000-1100	960-1080	1065-1080	945-1200	960-1080
Specific Heat(Btu/lb.°F)	0.23	0.23	0.23			
Coefficient of Thermal Expansion (in./in.°F)	11.8	11.7	11.5	10.3	11.7	11.3
Thermal Conductivity (Btu/fthr.°F)	65.3	55.6	55.6	67.7	78.6	56
Electrical Conductivity (% IACS)	29	31	23	31	25	23
Modulus of Elasticity (10⁶ psi)	10.3	10.3	10.3	10.3	11.9	10.3

Properties of Aluminum Alloys

Tabulated in accordance with the Unified Numbering System for Metals and Alloys (UNS), Society of Automotive Engineers, Warrendale, Pa., 1975. This reference contains the cross reference numbers for AISI, ASTM, FED, MIL SPEC, and SAE specifications. These are typical properties for sizes of about 1/2 inch. A typical value may be neither the mean nor the minimum. It is a value which can be obtained when the purchase specifications are carefully written and with continuous inspection and testing. The values given for fatigue strength, S_f , correspond to 50×10^7 cycles of completely reversed stress. Aluminum alloys do not have an endurance limit. The yield strength is 0.2% offset value. Multiply strength in kpsi by 6.89 to get strength in MPa.

Properties of Aluminum Alloys							
UNS Alloy Number	Temper	Yield Strength (kpsi)	Tensile Strength (kpsi)	Shear Modulus of Rupture (kpsi)	Fatigue Strength (kpsi)	Elongation in 2 in., %	Brinell Hardness (H _b)
A91100	-O	5	13	9.5	5	45	23
A91100	-H12	14	15.5	10	6	25	28
A91100	-H14	20	22	14	9	16	40
A91100	-H16	24	26	15	9.5	14	47
A91100	-H18	27	29	16	10	10	55
A93003	-O	6	16	11	7	40	28
A93003	-H12	17	19	12	8	20	35
A93003	-H14	20	22	14	9	16	40
A93003	-H16	24	26	15	9.5	14	47
A93003	-H18	27	29	16	10	10	55
A93004	-O	10	26	16	14	25	45
A93004	-H32	22	31	17	14.5	17	52
A93004	-H34	27	34	18	15	12	63
A93004	-H36	31	37	20	15.5	9	70
A93004	-H38	34	40	21	16	6	77
A92011	-T3	48	55	32	18	15	95
A92011	-T8	45	59	35	18	12	100
A92014	-O	14	27	18	13	18	45
A92014	-T4	40	62	38	20	20	105
A92014	-T6	60	70	42	18	13	135
A92017	-O	10	26	18	13	22	45
A92017	-T4	40	62	38	18	22	105

A92018	-T61	46	61	39	17	12	120
A92024	-O	11	27	18	13	22	47
A92024	-T3	50	70	41	20	16	120
A92024	-T4	48	68	41	20	19	120
A92024	-T36	57	73	42	18	13	130
A95052	-O	13	28	18	17	30	45
A95052	-H32	27	34	20	17.5	18	62
A95052	-H34	31	37	21	18	14	67
A95052	-H36	34	39	23	18.5	10	74
A95052	-H38	36	41	24	19	8	85
A95056	-O	22	42	26	20	35	
A95056	-H18	59	63	34	22	10	
A95056	-H38	50	60	32	22	15	
A96061	-O	8	18	12.5	9	30	30
A96061	-T4	21	35	24	13.5	25	65
A96061	-T6	40	45	30	13.5	17	95
A97075	-T6	72	82	49	24	11	150

Wrought Aluminum Alloys

Aluminum and its alloys are divided into two broad classes, castings and wrought (mechanically worked products). The latter is sub-divided into heat-treatable and non-heat-treatable alloys, and into various forms produced by mechanical working.

Wrought Aluminum Alloys		
Series	Main Alloy	Alloy Properties
1xxx	None (99% alu)	Unalloyed aluminum is highly corrosion resistant, low strength, workable, conductive. Non-heat-treatable.
2xxx	Copper	Gives strength, hardness, machinability. Heat-treatable.
3xxx	Manganese	Adds moderate strength, good workability. Non-heat-treatable.
4xxx	Silicon	
5xxx	Magnesium	Moderate to high strength. Corrosion resistant. Non-heat-treatable.
6xxx	Magnesium & Silicon	Increases strength, formability, corrosion resistance. Heat-treatable.
7xxx	Zinc	For greatest strength. Heat treatable. Other alloying elements such as copper, magnesium, chromium and zirconium may be specified.
8xxx	Tin, Lithium & Other elements.	Effects vary.
9xxx	N/A	(This series is unused presently.)

Casting Alloys

Series	Main Alloy	Alloy Notes
1xx.x	None (99% alum.)	Unalloyed aluminum.
2xx.x	Copper	Used extensively for applications where excellent strength and hardness at high temperatures are required. Heavy-duty pistons; motorcycle, diesel and aircraft pistons; aircraft generator housings; and air-cooled cylinder heads are typical applications.
3xx.x	Silicon	Other alloying elements such as copper and magnesium are specified. Typical applications are airframe castings, machine parts, truck chassis parts, aircraft and missile components, and structural parts requiring high strength.
4xx.x	Silicon	
5xx.x	Magnesium	Alloys possess a high and stable combination of strength, shock resistance and ductility. It is ideally suited for parts in instruments and computing devices where dimensional stability is of major importance.
6xx.x	N/A	(This series is unused presently.)
7xx.x	Zinc	Employed when a combination of good mechanical properties without heat treatment is needed. It also shows good shock and corrosion resistance and good machinability and dimensional stability.
8xx.x	Tin	
9xx.x	N/A	(This series is unused presently.)

Aluminum Temper Designations

Aluminum Temper Designations	
F	As fabricated. No control over the amount of strain hardening.
H	Strain-hardened (wrought products only) to increase strength.
H1	Strain-hardened only. Products are strain-hardened to achieve the strength desired without additional thermal treatment.
H1x,H2x,H3x	The second digit following the designations H1, H2, H3 indicate the final degree of strain hardening. The number 8 has been assigned to tempers having a final degree of strain-hardening equivalent to that resulting from approximately 75 % reduction in area. Tempers between that of the 0 Temper (annealed) and 8 (full hard) are designated by the numbers 1 through 7. A number 4 (which is halfway between 0 and 8) designation is considered half-hard; number 2 is considered quarter-hard; and the number 6 is three-quarter hard. When the number is odd, the limits of ultimate strength are exactly halfway between those of the even numbered tempers.
Hxxx	The third digit indicates a variation of the two digit H temper. It is used when the degree of temper is close to the 2 digit H temper.
H111	Applies to alloys which are strain-hardened less than the amount required for a controlled H11 temper.
H112	Applies to alloys that acquire some temper from shaping processes which do not have special control over the amount of strain-hardening or thermal treatment, but for which there are mechanical property limits.
H2	Strain-hardened and partially annealed. Applies to alloys 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 soften with age at room temperature, the H2 tempers have the same minimum tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum tensile strength as the corresponding H1 tempers and slightly higher elongation.
H3	Strain-hardened and stabilized. Applies to alloys that are strain-hardened and whose mechanical properties are stabilized by a low temperature thermal treatment that results in slightly lowered tensile strength and improved ductility. This designation is applicable only to those alloys that unless they are stabilized, will gradually soften with age at room temperature.
H311	Applies to alloys which are strain-hardened less than the amount required for a controlled H31 temper.
H321	Applies to alloys which are strain-hardened less than the amount required for a controlled H32 temper.
H323	Applies to products which are fabricated to have good resistance to stress corrosion cracking.
H343	Applies to products which are fabricated to have good resistance to stress corrosion cracking.

O	Annealed, recrystallized (wrought products only). Applies to wrought alloys which are annealed to obtain the softest temper, and to cast alloys which are annealed to improve ductility and dimensional stability.
T	Thermally treated to produce stable tempers other than F, O or H.
T1	Naturally aged. Product is cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.
T2	Annealed (cast products only). Applies to alloys which are cold worked to improve strength after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening is significant in mechanical property limits.
T3	Solution heat-treated, cold worked and naturally aged to a substantially stable condition to improve strength.
T4	Solution heat-treated and naturally aged to a substantially stable condition.
T5	Cooled from an elevated temperature shaping process and the artificially aged.
T51	Stress relieved by stretching. Applies to the following products when stretched the indicated amounts after solution heat-treatment or cooled from a high temperature shaping process: Plate—1.5-3% permanent set; Rod, bar, shapes, and extruded tubes—1-3% permanent set; Drawn tubes— 1.5-3% permanent set. Applies directly to plate, and rolled or cold finished rod and bar which receive no further straightening after stretching. Applies to extruded rod, bar, shapes, tubing, and to drawn tubing when designated as follows: T510 Products that receive no further straight ending after stretching; T511 Products that may receive minor straightening after stretching to comply with standard tolerances.
T52	Stress-relieved by compressing. Applies to alloys which are stress-relieved by compressing after solution heat-treatment, or cooled from a high temperature shaping process to produce a permanent set of 1 to 5%.
T54	Stress-relieved by combined stretching and compressing. Applicable to die forging which are stress-relieved by restring cold in the finish die.
T6	Solution heat-treated and then artificially aged. T62 indicates material is solution heat-treated from the O or F temper to demonstrate response to heat-treatment, and artificially aged.
T7	Solution heat-treated and then stabilized to carry them beyond the point of maximum strength to provide control of some special property.
T8	Solution heat-treated, cold worked, and then artificially aged.
T9	Solution heat-treated, artificially aged, and then cold worked.
T10	Artificially aged and then cold worked.
T42	(Wrought products only). Applicable to products solution heat-treated and naturally aged which have mechanical properties different from those of the T4 temper.
T62	(Wrought products only). Applicable to products solution heat-treated and artificially aged which have mechanical properties different from those of the T6 temper.
W	Solution heat treated. An unstable temper applied only to alloys which spontaneously age at room temperature after solution heat-treatment.

2. Beryllium

Beryllium has one of the highest melting points of the light metals. The modulus of elasticity of beryllium is approximately 1/3 greater than that of steel. It has excellent thermal conductivity, is nonmagnetic and resists attack by concentrated nitric acid. It is highly permeable to X-rays, and neutrons are liberated when it is hit by alpha particles, as from radium or polonium (about 30 neutrons/million alpha particles). At standard temperature and pressures beryllium resists oxidation when exposed to air (although its ability to scratch glass is probably due to the formation of a thin layer of the oxide). Beryllium is a very light weight metal with a high modulus of elasticity (five times that of ultrahigh-strength steels), high specific heat, and high specific strength (strength to weight ratio).

Uses

Beryllium is used as an alloying agent in the production of beryllium-copper because of its ability to absorb large amounts of heat. Beryllium-copper alloys are used in a wide variety of applications because of their electrical and thermal conductivity, high strength and hardness, nonmagnetic properties, along with good corrosion and fatigue resistance. These applications include the making of spot-welding electrodes, springs, non-sparking tools and electrical contacts.

Due to their stiffness, light weight, and dimensional stability over a wide temperature range, beryllium-copper alloys are also used in the defense and aerospace industries as light-weight structural materials in high-speed aircraft, missiles, space vehicles and communication satellites.

Thin sheets of beryllium foil are used with X-ray detection diagnostics to filter out visible light and allow only X-rays to be detected.

In the field of X-ray lithography beryllium is used for the reproduction of microscopic integrated circuits.

Because it has a low thermal neutron absorption cross section, the nuclear power industry uses this metal in nuclear reactors as a neutron reflector and moderator.

Beryllium is used in nuclear weapons for similar reasons. For example, the critical mass of a plutonium sphere is significantly reduced if the plutonium is surrounded by a beryllium shell.

It is, however, brittle, chemically reactive, expensive to refine and form, and its impact strength is low compared to values for most other metals.

3. Copper

Copper provides a diverse range of properties: good thermal and electrical conductivity, corrosion resistance, ease of forming, ease of joining, and color. However, copper and its alloys have relatively low strength-to-weight ratios and low strengths at elevated temperatures. Some copper alloys are also susceptible to stress-corrosion cracking unless they are stress relieved. Next to silver, copper is the next best electrical conductor. It is a yellowish red metal that polishes to a bright metallic luster. It is tough, ductile and malleable. Copper has a disagreeable taste and a peculiar smell. Copper is resistant to corrosion in most atmospheres including marine and industrial environments. It is corroded by oxidizing acids, halogens, sulphides and ammonia based solutions.

Copper and its alloys -- the brasses and bronzes -- are available in rod, plate, strip, sheet, tube shapes, forgings, wire, and castings.

4. Lead

Lead is the most impervious of all common metals to X-rays and gamma radiation and it resists attack by many corrosive chemicals, most types of soil, and marine and industrial environments. Main reasons for using lead often include low melting temperature, ease of casting and forming, high density, good sound and vibration absorption, and ease of salvaging from scrap. Sheet lead, lead-loaded vinyls, lead composites, and lead-containing laminates are used to reduce machinery noise. The natural lubricity and wear resistance of lead make the metal suitable, in alloys, for heavy-duty bearing applications such as railroad-car journal bearings and piston-engine crank bearings.

5. Magnesium

As the lightest structural metal available, magnesium has a high strength-to-weight ratio. With its low modulus of elasticity combined with moderate strength, magnesium alloys can absorb energy elastically, providing excellent dent resistance and high damping capacity. Magnesium has good fatigue resistance and performs particularly well in applications involving a large number of cycles at relatively low stress. The metal is sensitive to stress concentration, however, so notches, sharp corners, and abrupt section changes should be avoided. Magnesium alloys are the easiest of the structural metals to machine and they can be shaped and fabricated by most metalworking processes, including welding.

6. Nickel

Nickel fits many applications that require specific corrosion resistance or elevated temperature strength. Some nickel alloys are among the toughest structural materials known. When compared to steel, other nickel alloys have ultrahigh strength, high proportional limits, and high moduli of elasticity. Commercially pure nickel has good electrical, magnetic, and magnetostrictive properties.

7. Precious Metals

- **Gold** is an extremely inert, soft, ductile metal, that undergoes very little work hardening. A gram of pure gold can be worked into leaf covering 6 ft² and only 0.0000033 in. thick. It is used chiefly for linings or electrodeposits and is often alloyed with other metals such as copper or nickel to increase strength or hardness.
- **Silver** is a very malleable, ductile, and corrosion resistant metal that has the highest thermal and electrical conductivity of all metals and is the least costly of all the precious metals. Alloyed with copper, and sometimes with zinc, silver is also used in high-melting temperature solders.
- **Platinum** is an extremely malleable, ductile, and corrosion resistant silver-white metal. When heated to redness, it softens and is easily worked. It is nearly nonoxidizable and is soluble only in liquids that generate free chlorine such as aqua regia. Because platinum is inert and stable, even at high temperatures, the metal is used for high-temperature handling of high-purity chemicals and laboratory materials. Other applications include electrical contacts, resistance wire, thermocouples, and standard weights.

8. Refractory Metals

Refractory metals are characterized by their extremely high melting points, which range well above those of iron, cobalt, and nickel. They are used in demanding applications requiring high-temperature strength and corrosion resistance. The most extensively used of these metals are tungsten, tantalum, molybdenum, and columbium (niobium).

9. Tin

Tin is characterized by a low-melting point (450°F), fluidity when molten, readiness to form alloys with other metals, relative softness, and good formability. The metal is nontoxic, solderable, and has a high boiling point. The temperature range between melting and boiling points exceeds that for nearly all other metals (which facilitates casting). Upon severe deformation, tin and tin-rich alloys work soften. Principal uses for tin are as a constituent of solder and as a coating for steel (tinplate, or terneplate). Tin is also used in bronze, pewter, and bearing alloys.

10. Titanium

There are three structural types of titanium alloys:

- Alpha Alloys are non-heat treatable and are generally very weldable. They have low to medium strength, good notch toughness, reasonably good ductility and possess excellent mechanical properties at cryogenic temperatures. The more highly alloyed alpha and near-alpha alloys offer optimum high temperature creep strength and oxidation resistance as well.
- Alpha-Beta Alloys are heat treatable and most are weldable. Their strength levels are medium to high. Their hot-forming qualities are good, but the high temperature creep strength is not as good as in most alpha alloys.
- Beta or near-beta alloys are readily heat treatable, generally weldable, capable of high strengths and good creep resistance to intermediate temperatures. Excellent formability can be expected of the beta alloys in the solution treated condition. Beta-type alloys have good combinations of properties in sheet, heavy sections, fasteners and spring applications.

11. Zinc

Zinc, a crystalline metal with moderate strength and ductility, is seldom used alone except as a coating. In addition to its metal and alloy forms, zinc also extends the life of other materials such as steel (by hot dipping or electrogalvanizing), rubber and plastics (as an aging inhibitor), and wood (in paints). Zinc is also used to make brass, bronze, and die-casting alloys in plate, strip, and coil; foundry alloys; superplastic zinc; and activators and stabilizers for plastics.

Zinc is a silvery blue-grey metal with a relatively low melting point (419.5°C) and boiling point (907°C). When unalloyed, its strength and hardness is greater than that of tin or lead, but appreciably less than that of aluminium or copper. The pure metal cannot be used in stressed applications due to low creep-resistance. For these reasons most uses of zinc are after alloying with small amounts of other metals or as a protective coating for steel.

Uses

One of the most useful characteristics of zinc is its resistance to atmospheric corrosion, and just over half of its use is for the protection of steelwork. In addition to its metal and alloy forms, zinc also extends the life of other materials such as steel (by hot dipping or electrogalvanizing), rubber and plastics (as an aging inhibitor), and wood (in paints). Zinc is also used to make brass, bronze, and die-casting alloys in plate, strip, and coil; foundry alloys; superplastic zinc; and activators and stabilizers for plastics.

Mechanical and physical properties -

Tensile strength (cast) : 28MN/m² (4,000 psi)

- (rolled - with grain)

- (99.95% zinc soft temper) : 126MN/m² (18,000 psi)

- (98.0% zinc hard temper) : 246MN/m² (35,000 psi)

Elongation :

- (rolled - with grain)

- (99.95% zinc soft temper) : 65%

- (98.0% zinc hard temper) : 5%

Modulus of elasticity : 7 X 10⁴ MN/m² (1 X 10⁷ psi)

Brinell hardness, 500 kg load :

- for 30 sec. : 30

Impact resistance :

- (pressed zinc, elongation = 30%) : 6.5-9 J/cm² (26-35 ft-lbs/in²)

Surface tension - liquid (450°C) : 0.755 N/m

Surface tension - liquid (419.5°C) : 0.782 N/m

Viscosity-liquid (419.5°C) : 0.00385 N/m

Velocity of sound (20°C) : 3.67 km/s

Coefficient of friction :

- (rolled zinc v rolled zinc) : 0.21

Hardness : 2.5 mohs

12. Zirconium

Relatively few metals besides zirconium can be used in chemical processes requiring alternate contact with strong acids and alkalis. Major uses for zirconium and its alloys are as a construction material in the chemical-processing industry.