Mid-Atlantic Casting Services

A Guide to Aluminum Casting Alloys

The specification of an aluminum alloy for a cast component is based upon the mechanical properties it can achieve. For the designer and purchaser, it is vital to understand that the properties obtained from one particular combination of casting alloy, foundry practice and thermal treatment may not be identical to those achieved with the same alloy in a different foundry or with a different thermal treating source. In all aluminum casting alloys, the percentages of alloying elements and impurities must be controlled carefully. If they are not, characteristics such as soundness, machinability, corrosion resistance and conductivity are affected adversely.

For example, calcium and sodium, within a few thousandths of a percent, can have either a beneficial or detrimental effect upon both the soundness and machinability of alloys containing a high percentage of silicon (Si). Similarly, the use of phosphorus in controlled amounts has a beneficial effect on the hypereutectic aluminum-silicon alloys containing Si in excess of 12%.

Special mechanical properties are obtained in many alloys through accurate control of chemistry, manufacturing and heat treating. Reliable ingot producers can supply foundries with ingot and heat treating specifications designed to obtain specific mechanical properties. However, while certain mechanical properties are improved, it is at the expense of others. For example, tensile and yield strengths can be increased, but this results in lower elongation and higher hardness. Higher elongation and lower hardness result in losses in tensile and yield strengths.

Thermal Treatment

Sand and permanent mold castings may be heat-treated to improve mechanical and physical properties. Die castings only can be stress relieved (and not solution heat-treated) because of their porous internal structure with gas inclusions, which may blister at high temperatures. Some alloys, such as 443.0 (which is cast in sand or permanent molds but contains little or no copper, zinc or magnesium), do not respond to heat treatment to increase mechanical properties.

Following are thermal treatment designations (tempers) and what they specify. For aluminum castings, "–T" designates thermal treatment and is always followed by one or more digits that indicate specific sequences of basic treatments. A second digit indicates a modification of the heat treatment to obtain specific properties.

F*—As-cast.*

O*—Stress relieve or anneal.*

–T4*—Solution heat treat and quench.* This is an unstable treatment. While it improves mechanical properties (such properties increase through aging at room temperature over a period of weeks), it is a usual practice to artificially age to attain maximum mechanical values.

–T5, –T51*—Artificially age.* This type of heat treatment is done at a comparatively low temperature and serves to eliminate growth of thermal cycle. It also is used to stabilize castings dimensionally (improving mechanical properties somewhat) to improve machinability and to relieve stress.

–T6, –T61*—Solution heat treat, quench and artificially age.* Such heat treatment usually results in maximum tensile and yield strengths with adequate elongation. Aging stabilizes the properties.

–T7, –T71*—Solution heat treat, quench and artificially overage.* This heat treatment improves mechanical properties to a large degree, stabilizes the castings, and usually results in a slightly lower tensile and yield strength but an increased elongation value compared to the –T6 series of heat treatments.

Alloy Choice

Choosing the alloy, casting process and thermal treatment requires a knowledge of the service conditions of the part under consideration. More than 60 casting alloys are in use today, with up to five different thermal treatment options. This results in a large number of alternatives to choose from to satisfy individual requirements. Because of these many alloy and thermal treatment combinations, the possible range of typical mechanical properties varies widely. Since commercial castings often do not have critical service requirements, the foundry should be consulted as to the most economical alloy and production method for the job.

In most cases, aluminum castings are designed for maximum efficiency. In such cases, the alloy and heat treatment must be selected carefully. Designers, with their knowledge of the service requirements for the casting, must confine the alloy choice to those that provide the necessary properties and then must be guided by the foundry for the final choice.

Sometimes, the alloy that shows the best properties on paper may have production characteristics that make it less desirable on an overall basis than other eligible alloys. The foundry is in the best position to advise on such factors as availability, relative ingot costs, production costs and reproducibility of results. When this is coordinated with the designer's knowledge of service requirements, such as strength, hardness, corrosion resistance, impact strength and machinability, the best possible selection will result.

Because of this coordination, changes from the initial design may be indicated to improve design efficiency and/or lower production costs. For instance, a casting with sound design from other standpoints may have a size or shape conducive to distortion in heat treating, which could be minimized through design changes.

Production and service requirements have a large bearing on the casting method, as do the size and shape of the part. For example, castings required in large numbers must be made either by the permanent mold, diecasting or automated sand casting processes, provided the size and design features of the casting and available alloys are suitable.

Sand casting often is used to produce parts with hollow cavities and a complex arrangement of ribs, pockets, etc., and for parts unsuitable for casting in metal molds. In some cases, it is advantageous to redesign a casting for either permanent mold or diecasting methods. Sand casting usually requires minimum tooling charge, but the unit price of the castings and the finished part can be high. Permanent mold casting requires a higher tooling charge, but the unit price is lower, particularly for longer runs. Diecasting usually requires the highest tooling charge but also the lowest piece price on large quantities.

Once the casting method is determined, the alloy choice is narrowed (because not all alloys can be used with all casting methods). The next considerations are the service requirements. If high strength is required, heat-treatable alloys must be used. Alloy choice can be narrowed further when remaining requirements, such as pressure tightness, corrosion resistance and machinability, are considered.

In some instances, it may be required to maximize one certain property—for example, highest possible yield strength. This limits the alloy and heat treatment choices, as well as the casting method, to one or two choices. In addition, compromises will have to be made on the other requirements, such as ductility.

Alloy Designations

Aluminum casting alloys in the U.S. are numbered according to a three-digit (plus decimal) system adopted by the Aluminum Assn. (AA) in 1954 and approved by the American National Standards Institute in 1957 (ANSI H35.1). The American Society for Testing and Materials (ASTM), the Society of Automotive Engineers (SAE), and the Federal and Military specifications for aluminum castings conform to the AA designation system.

Table 1. Aluminum Alloy Classification System

Series	Alloy Type
1XX.X	99.0% Minimum Aluminum
2XX.X	Aluminum + Copper
3XX.X	Al + (Si-Mg), (Si-Cu) or (Si-Mg-Cu)
4XX.X	Aluminum + Silicon
5XX.X	Aluminum + Magnesium
7XX.X	Aluminum + Zinc
8XX.X	Aluminum + Tin

In this system, major alloying elements and certain combinations of elements are indicated by the number series in Table 1. The 6XX.X and 9XX.X series are not currently in use, but they are being held open for possible use in the future. The digit following the decimal in each alloy number indicates the form of product:

- a “0” (zero) following the decimal indicates the chemistry limits applied to an alloy casting;
- a “1” (one) following the decimal indicates the chemistry limits for ingot used to make the alloy casting;
- a “2” (two) following the decimal also indicates ingot but with somewhat different chemical limits (typically tighter, but still within the limits for ingot).

Generally, the XXX.1 ingot version can be supplied as a secondary product (remelted from scrap, etc.), whereas the XXX.2 ingot version is made from primary aluminum (reduction cell).

Some alloy names include a letter. Such letters, which precede an alloy number, distinguish between alloys that differ only slightly in percentages of impurities or minor alloying elements (for example, 356.0, A356.0, B356.0 and F356.0).

Table 2 displays the mechanical properties of some common aluminum casting alloys. The properties shown for the alloys were obtained from ASTM, SAE and federal specifications for sand, permanent mold and diecasting. Chemical composition limits are for standard foundry alloy ingot, percent maximum, unless shown as a range. The remainder is aluminum.\

Table 2. Typical Mechanical Properties of Common Aluminum Alloys

Alloy	Casting process & temper	Tension			Shearing strength (ksi)	Compressive yield strength (set 0.2%) (ksi)	Brinell hardness (500 kg load on 10 mm ball)	Endurance limit (ksi)
		Ultimate strength (ksi)	Yield strength (set 0.2%) (ksi)	Elongation (% in 2 in.)				
242.0	Sand[1]—F	31	30	<0.5	—	—	—	—
	Sand—O	27	18	1.0	21	18	70	8
	Sand—T571	32	30	0.5	26	34	85	11
	Sand—T77	30	23	2	24	24	75	10.5
	PM[2]—T571	40	34	1	30	34	105	10.5
	PM—T61	47	42	0.5	35	44	110	9.5
	Sand—T75	31	—	2	—	—	75	—
308.0	PM—F	28	16	2	22	17	70	13
319.0	Sand—F	27	18	2	22	19	70	10
	Sand—T5	30	26	1.5	24	27	80	11
	Sand—T6	36	24	2	29	25	80	11
	PM—F	34	19	2.5	24	19	85	—
	PM—T6	40	27	3	—	27	95	—
356.0	Sand—F	24	18	6.0	—	—	—	—
	Sand—T51	25	20	2	20	21	60	8
	Sand—T6	33	24	3.5	26	25	70	8.5
	Sand—T7	34	30	2	24	31	75	9
	Sand—T71	28	21	3.5	20	22	60	8.5
	PM—F	26	18	5	—	—	—	—
	PM—T51	27	20	2	—	—	—	—
	PM—T6	38	27	5	30	27	80	13
	PM—T7	32	24	6	25	24	70	11
A356.0	Sand—F	23	12	6	—	—	—	—
	Sand—T51	26	18	3	—	—	—	—
	Sand—T6	40	30	6	—	—	75	—
	Sand—T71	30	20	3	—	—	—	—
	PM—F	27	13	8	—	—	—	—
	PM—T51	29	20	5	—	—	—	—
	PM—T6	41	30	12	—	—	80	—
	PM—T61	41	30	10	28	32	90	13
A380.0	Die[3]—F	48	24	3	31	80	21	
A390.0	PM—F & T5	29	29	<1	—	—	110	—
	PM—T6	45	45	<1	—	60	145	17
	PM—T7	38	38	<1	—	51.7	120	14.5
	Sand—F & T5	26	26	<1	—	—	100	—
	Sand—T6	40	40	<1	—	—	140	13
	Sand—T7	36	36	<1	—	—	115	—
B390.0	Die—F	40.5	35	1	—	—	120	20
	Die—T5	43	38.5	1	—	—	—	—
535.0	Sand—F	40	20	13	27.45	35.5	70	10
712.0	Sand—F	35[4]	25[4]	5[4]	26	17	75[4]	9

[1] Green or chemically bonded sand casting. [2] Permanent mold casting. [3] Diecasting. [4] Test performed 30 days after casting.

Alloys 242.0 and A242.0

Alloys 242.0 and A242.0 are used extensively for applications where strength and hardness at high temperatures are required. Typical applications include: heavy-duty pistons; motorcycle, diesel and aircraft pistons; aircraft generator housings; and air-cooled cylinder heads.

Castability—These alloys have good fluidity, are fair for pressure tightness, and show fair resistance to hot cracking and solidification shrinkage.

Machinability—Machining characteristics are good. The usual precautions for machining aluminum will give the best results.

Finishing—Electroplated finishes are excellent on both alloys. Mechanical finishes are good and anodized appearance is good.

Weldability—Arc and resistance methods are good for welding these alloys. Gas welding is satisfactory, but brazing is not recommended.

Corrosion Resistance—The resistance of these alloys to most forms of common corrosion is fair. Some additional protection can be gained by using chemical conversion coatings.

Alloys 319.0, A319.0, B319.0 and 320.0

Alloys 319.0 and A319.0 exhibit good castability, weldability, pressure tightness and moderate strength and are stable in that their casting and mechanical properties are not affected by fluctuations in the impurity content. Alloys B319.0 and 320.0 show higher strength and hardness than 319.0 and A319.0 and are generally used with the permanent mold casting process. Characteristics other than strength and hardness are similar to those of 319.0 and A319.0.

Typical applications for sand castings of these alloys include: internal combustion and diesel engine crankcases; gasoline and oil tanks; and oil pans. Permanent mold cast components include: water-cooled cylinder heads, rear axle housings and engine parts.

Castability—These alloys all exhibit good pressure tightness, fluidity, resistance to hot cracking and solidification shrinkage tendencies.

Machinability—Machining characteristics are good. To preclude possible adverse effects of abrasiveness and inclusions, carbide-tipped tools are recommended.

Finishing—Electroplated finishes are good on these alloys. Mechanical and anodized finishes are fair.

Weldability—Arc welding results in the most satisfactory welds. Resistance and gas methods are both good. Brazing is not recommended.

Corrosion Resistance—These alloys exhibit good resistance to most common forms of corrosion and react well to chemical conversion coatings for additional protection.

Alloy 356.0

Applications for 356.0 are similar to those for 355.0. Alloy 356.0 has excellent casting characteristics and has largely replaced alloy 295.0.

Permanent mold castings of this alloy are used for machine tool parts, aircraft wheels and hand wheels, pump parts, tank car fittings, marine hardware, valve bodies and bridge railing parts, as well as for aileron control sectors, rudder control supports, fuselage fittings and fuel tank elbows for airplanes and missiles. Automotive applications include miscellaneous castings for trucks and trailers, spring brackets, cylinder heads, engine blocks, passenger car wheels and transmission cases.

Uses for sand castings of 356.0 include flywheel housings, automotive transmission cases, oil pans, rear axle housings, brackets, water-cooled cylinder blocks, various fittings and pump bodies. This alloy is used in various marine applications in the T6 condition where pressure tightness and/or corrosion resistance are major requirements.

Castability—Fluidity, resistance to hot cracking and resistance to solidification shrinkage are all excellent for 356.0.

Machinability—After heat treatment (notably in the T6 condition), 356.0 has good machinability. Because of the high Si content, savings can be realized by using carbide-tipped cutting tools.

Rakes must be positive and high. Speeds must approach the maximum, and light cuts must be taken.

Finishing—Alloy 356.0 has good polishing characteristics. It is excellent for electroplating and good for chemical conversion coatings. Anodizing appearance is good, and the color is gray.

Weldability—Good welding characteristics are shown by 356.0 for all standard welding methods. The alloy is not brazed.

Corrosion Resistance—Excellent resistance to corrosion is shown by 356.0. Chemical conversion coatings give further protection.

Alloy A356.0

Alloy A356.0 has greater elongation, higher strength and considerably higher ductility than 356.0. It has these improved mechanical properties because impurities are lower in A356.0 than in 356.0. Typical applications are airframe castings, machine parts, truck chassis parts, aircraft and missile components, and structural parts requiring high strength.

Castability—All casting characteristics are excellent for this alloy.

Machinability—Alloy A356.0 has good machinability. Abrasiveness can be overcome and high tool wear can be minimized by using sharp, carbide-tipped tools with high rakes and clearances. Moderate to fast speeds are recommended.

Finishing—Electroplated finishes are good. Chemical conversion coatings give good protection, but anodized appearance is only fair. Mechanical finishes on A356.0 are good.

Weldability—All common welding methods are excellent for joining this alloy. Brazing is not performed.

Corrosion Resistance—This alloy has good resistance to most forms of corrosion.

Alloys A380.0 and B380.0

These alloys are used for casting general-purpose die castings. They have good mechanical properties and are used to make housings for lawn mowers and radio transmitters, air brake castings, gear cases and air-cooled cylinder heads.

Castability—Fluidity, pressure tightness and resistance to hot cracking all are good.

Machinability—Although the machinability of A380.0 and B380.0 is considered good, carbide-tipped tooling is recommended because of the alloys' tendency to be abrasive. Tools should be sharp with high rake and clearance angles, and machines should be operated at moderate to fast speeds and feeds.

Finishing—Electroplating provides an excellent finish on these alloys. Mechanical and anodized finishes are good.

Weldability—Welding of A380.0 and B380.0 is fair for all common types of welding processes. Brazing is not employed.

Corrosion Resistance—These alloys have only fair resistance to most corrosive atmospheres, and the protective value of chemical conversion coatings is poor.

Alloys A390.0 and B390.0

These companion alloys are hypereutectic aluminum-silicon alloys. The optimum structure of either alloy must consist of fine, uniformly distributed primary Si crystals in a eutectic matrix. This alloy does not require heat treatment, which may eliminate internal stresses that may cause fatigue failure.

The low coefficient of thermal expansion, high hardness and good wear resistance of these alloys make them suitable for internal combustion engine pistons and blocks and cylinder bodies for compressors, pumps and brakes.

Castability—For alloy B390.0, the diecastability rating is good, and relatively thin and intricate sections can be produced. Pressure tightness and resistance to hot cracking are good. Resistance to die soldering is excellent.

For A390.0, permanent mold castability is good. Sand castability is only good because the slower cooling rates adversely affect casting microstructure. Pressure tightness and resistance to hot cracking are good. Gating designs for proper directional solidification and feeding are essential for sound castings. Pressure tightness is rated good.

Machinability—Tool life when machining A390.0 or B390.0 is at its best with adequate refinement of primary Si crystals. Cutting tools of cast iron cutting grade carbide and M-7 tool steel may be acceptable, but the recommended cutting material is polycrystalline diamond.

Alloys A390.0 and B390.0 require a cutting fluid in most operations. Many of the commercial water-emulsion cutting fluids are satisfactory. Aside from tool wearing, A390.0 and B390.0 alloys have excellent machining characteristics. Chips are short and easy to remove, and high-quality surface finishes are generated easily.

Weldability—Weldability is fair. The best processes are inert gas arc or oxyacetylene welding. Brazing is not recommended.

Corrosion Resistance—Resistance to corrosion is good to great, depending on the alloys' intended environments. Chemical conversion coatings increase corrosion resistance.

Alloy 535.0

Alloy 535.0 is an aluminum-magnesium alloy possessing a high, stable combination of strength, shock resistance and ductility. It is suited for parts in instruments and computing devices where dimensional stability is of major importance.

In addition to the high ductility and tensile strength of 535.0, the Charpy impact is 10–12 lb, which makes it suitable for shock-resistant applications. In addition, this alloy doesn't require heat treatment. Brackets, C-clamps and machined parts that need strength as well as impellers, optical equipment and similar applications requiring a high polish or anodized finish are typical uses. In many cases, this alloy has replaced gray iron and malleable iron because its use reduces weight without sacrificing strength.

Castability—The alloy has fair casting characteristics and attains its high physical and mechanical properties immediately upon casting. This fact is important to remember because most high-strength aluminum alloys change their properties as a result of age hardening. These properties remain constant for 535.0 within the entire range of temperatures from –76 to 225F (-60 to 107C). The alloy shows fair fluidity with little tendency toward hot tearing.

Machinability—The machinability of this alloy is excellent. Despite its high ductility, there is little tool drag. Machining is possible immediately following casting. An excellent surface finish is produced, especially when machined with carbide tools at maximum speeds.

Finishing—Because of this alloy's high resistance to corrosion, castings produced from it will not require any further surface treatment for most applications. However, it can be satin-anodized or chrome-plated for additional corrosion protection. Alloy 535.0 also can be anodized in a wide variety of colors. The lack of Si in the alloy provides satisfactory coloration.

Weldability—Alloy 535.0 can be welded by any of the inert gas or shielded arc methods using filler material of 5356, 5183 or 1100 welding wire or rod, or using clean scraps or cast pieces of 535.0. Fluxes should be avoided. Consequently, fusion welding processes requiring fluxes are not recommended.

Corrosion Resistance—Because of the almost complete absence of heavy metals, the corrosion resistance of 535.0 is extremely high. In addition, its relatively high magnesium content gives it further protection against corrosion from mild alkalis or salt spray.

Alloy 712.0

Alloy 712.0 is employed when a combination of good mechanical properties without heat treatment is needed. It also shows good shock, corrosion resistance, machinability and dimensional stability. No distortion is exhibited when 712.0 is heated. After brazing, the alloy will regain its original strength by natural aging.

The alloy is used for marine castings, farm machinery, machine tool parts and other applications in which the part must have good strength or impact resistance.

Castability—Alloy 712.0 has fair to good castability. Although its pressure tightness and resistance to hot cracking are only fair, the alloy's fluidity and solidification shrinkage tendency are rated as good.

Machinability—The machining characteristics of this alloy are excellent. Fast speeds and feeds and wear-resistant tools correctly ground for cutting aluminum are recommended.

Finishing—Polished finishes are good. The anodized finish is good, and the color is medium golden yellow.

Weldability—Welding characteristics are fair for most common methods. The alloy is recommended for brazing.

Corrosion Resistance—The alloy has good natural resistance to corrosion, and good additional protection is received from chemical conversion coatings.