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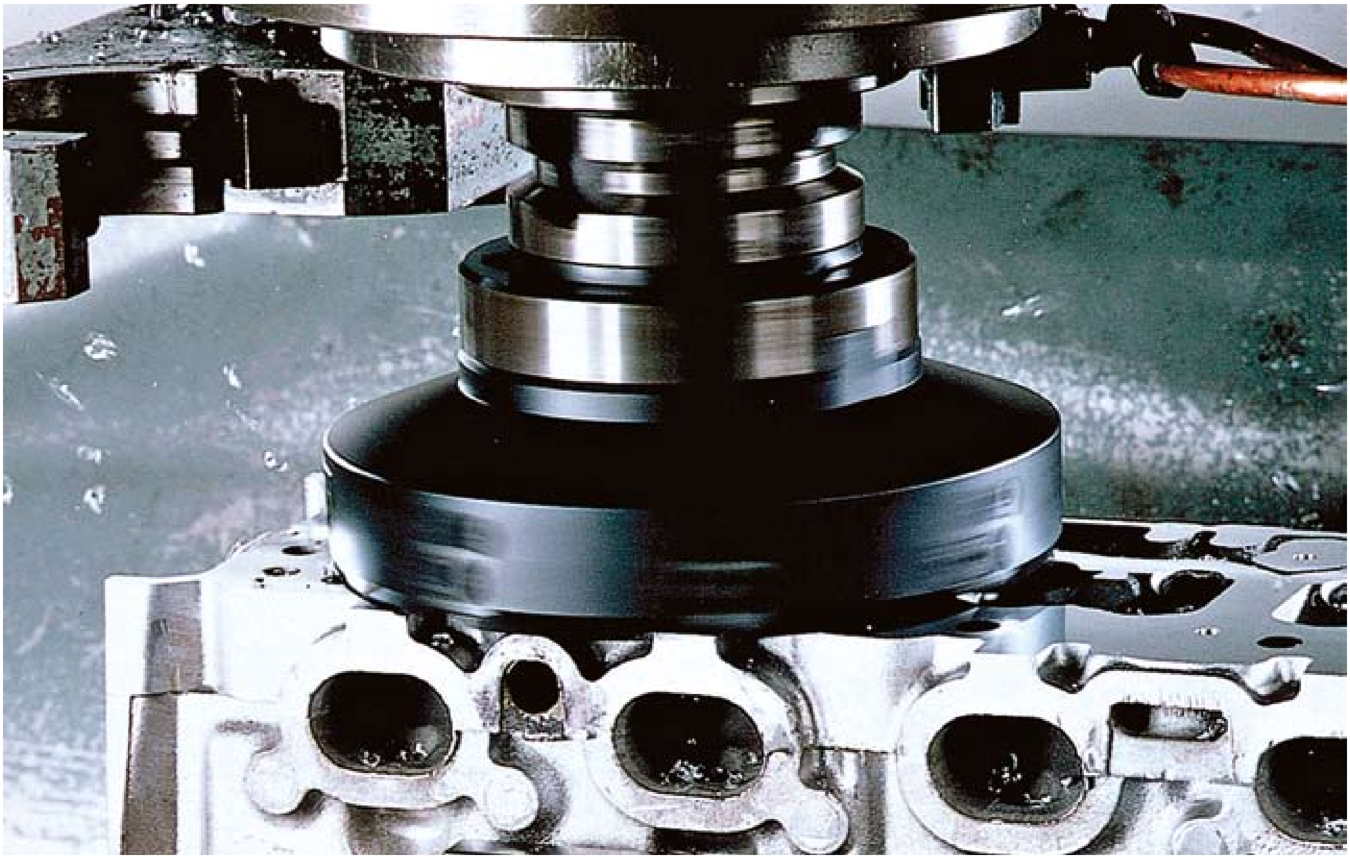

Sumitomo Electric Carbide

Cast Contents

Understanding the composition of cast aluminum alloys can increase machining productivity.

By Edmund Isakov, Ph.D.

Part 2 of 2

Aluminum is the third most abundant element in the earth's crust. As a metal workpiece, it is one of the most frequently machined.

The second part of this two-part article covers the designation system for cast aluminum and aluminum alloys and their temper (a process that improves physical and mechanical properties), the relationship between hardness of aluminum alloys and their strength, cutting data, and methods of calculating the machining power required to maximize productivity from a given machine tool. The first part, which appeared in the January issue, covered wrought aluminum and aluminum alloys.

Designation System

The designation system for cast aluminum and aluminum alloys is covered by the American National Standards Institute (ANSI) and registered with the Aluminum Association Inc. in the U.S.

A four-digit numerical designation system incorporating a decimal point is used to identify aluminum and aluminum alloys in the form of castings and foundry ingot. The first digit indicates the following groups:

- Aluminum greater than 99.00 percent is designated 1xx.x.

Aluminum alloys are grouped by major alloying element or elements.

- An aluminum alloy with copper as the major alloying element is designated 2xx.x.
- Silicon (Si) with added copper (Cu) and/or magnesium (Mg) is 3xx.x.
- Silicon is 4xx.x.
- Magnesium is 5xx.x.
- One unused series is 6xx.x.
- Zinc (Zn) with additions of copper, magnesium, chromium (Cr), manganese (Mn) or combinations of these elements is 7xx.x.
- Tin (Sn) is 8xx.x.
- Another unused series is 9xx.x.

In the 1xx.x group, the second two of four digits indicate the minimum aluminum percentage when expressed to the nearest 0.01 percent. These digits are the same as the two digits to the right of the decimal point. For example, the 100.1 grade is 99.00 percent aluminum, and the 170.1 grade is 99.70 percent aluminum. The last digit indicates the product form: 1xx.0 is for castings, and 1xx.1 is for ingot.

In the 2xx.x through 8xx.x designations for alloy groups, the second and third digits have no numerical significance but serve only to identify the various alloys in the group. A capital letter preceding the numerical designations indicates modification of the original alloys. Letter A indicates the first modification of the original alloy; letter B indicates the second modification of the same alloy and so on. Primarily, modifications indicate changes in the original alloys' chemical compositions. For example, 201.0 is the original sand casting alloy, and A201.0 is the first modification. The 201.0 alloy contains 0.10 percent Si, 0.15 percent Fe, 4.0 to 5.2 percent Cu, etc. The modified A201.0 contains 0.05 percent Si, 0.10 percent Fe, 4.0 to 5.0 percent Cu, etc.

The letters are assigned in alphabetical sequence starting with A but omitting I, O, Q and X, with X being reserved for experimental alloys. The last digit, which is to the right of the decimal point, indicates the product form: xxx.0 denotes castings, xxx.1 denotes standard ingot, and xxx.2 denotes ingot having composition ranges narrower than but within those of standard ingot (i.e., alloys 319.0, A319.0, B319.1, C355.2, etc.).

The temper designation system for cast aluminum alloys is similar to that for wrought ones. The same tempers (except type H, strain hardened, which pertains only to wrought ones) are applied to improve physical and mechanical properties of cast products.

- F (as fabricated) is applied to casting processes in which no special control over thermal conditions or strain hardening is employed.
- O (annealed) is applied to cast products to improve ductility and dimensional stability.
- T (solution heat-treated) and all subdivisions (T1 through T10) apply to products that have been strengthened by heat treatment, with or without subsequent strain hardening.

Cast Aluminum Alloys

The three most important methods of producing cast aluminum alloys are die casting, permanent mold casting and sand casting.

Die casting, in which molten metal is forced into a steel die, or mold, under pressure is normally employed for high-volume production. Die casting requires a minimum of machinery to produce accurate parts.

Permanent mold casting involves molds and cores typically made of steel. Molten metal is generally poured into the mold, but a vacuum is sometimes applied.

The most versatile method is sand casting. Virtually any pattern can be pressed into a fine sand mixture to form a mold into which the aluminum alloy is poured. This is a slow process, but usually more economical for small quantities, intricate designs or large castings.

In the U.S., transportation represents the largest market for wrought and cast aluminum alloys. Their applications in cars and light trucks accounted for almost 5.2×10^9 lbs. (2.4×10^6 tons) in 2000, and more than half of that amount was cast aluminum alloys.

Cast aluminum transmission housings and pistons have been universal in vehicles throughout the world for years. Auto applications grow as automakers and other transportation manufacturers seek new ways to reduce weight, improve fuel efficiency and enhance vehicle performance.

Due to space limitations this article briefly describes only three of six aluminum alloy groups: the commonly used alloys for automotive, aerospace and marine applications.

Aluminum-Copper Alloys

The majority of aluminum-copper alloy grades contain 4 to 5 percent copper (32 grades), two grades contain 6 to 8 percent copper (213.0 and 213.1), two grades contain 7 to 9 percent copper (240.0 and 240.1), and two grades contain 9.2 to 10.7 percent copper (222.0 and 222.1).

There are 17 grades of aluminum alloy castings (2xx.0) and 21 grades of aluminum alloy ingots (2xx.1 and 2xx.2). Among the 38 grades, there are 30 original alloys (201.0, 204.0, 206.2, 242.1, etc.) and eight modified alloys (A201.1, B201.0, A206.2, etc).

The following aluminum-copper alloys are typical workpiece materials for automotive and aerospace parts.

- The 201.0 grade [4.6 percent Cu, 0.7 percent silver (Ag), 0.35 percent Mn, 0.35 percent Mg and 0.25 percent titanium (Ti)] is used for making gasoline-engine cylinder heads and pistons, connecting rods, rocker arms, aircraft landing gears and pump housings.
- The 206.0 grade (4.5 percent Cu, 0.30 percent Mn, 0.25 percent Mg and 0.22 percent Ti) is used for making turbine and supercharger impellers, cylinder heads for gasoline and diesel motors, gear housings and other parts that require high strength at elevated temperatures.
- The 242.0 grade [4.0 percent Cu, 2.0 percent nickel (Ni) and 2.5 percent Mg] is used for making motorcycle, diesel and aircraft pistons; air-cooled cylinder heads; and other parts that require high-temperature strength.
- The 295.0 grade (4.5 percent Cu and 1.1 percent Si) is used for making flywheel housings, bus and aircraft wheels, fittings and crankcases.
- The 296.0 grade (4.5 percent Cu and 2.5 percent Si) is used for making aircraft fittings, aircraft wheels, compressor connecting rods and other parts requiring high tensile strength.

As an example, typical mechanical properties of 201.0 and 296.0 aluminum alloys are shown in Tables 1 and 2. Solution heat-treated temper T6 produces higher strength and hardness in the 201.0 alloy, and solution heat-treated temper T6 produces higher strength and hardness in the 296.0 alloy.

These alloys contain almost the same amount of copper (4.5 to 4.6 percent) but mainly differ in silicon content: 0.10 percent Si in the 201.0 alloy, and 2.5 percent Si in the 296.0 alloy. Higher silicon content increases fluidity and reduces hot shortness, but reduces ductility. That explains why the strength values of the 201.0 alloy are much higher than those of 296.0.

Aluminum-Silicon-Copper Alloys

Aluminum-silicon-copper alloys are the most commonly used in comparison with other groups. This group includes 112 grades—more than any other group. The majority of alloys in this group (70 grades) contain 5 to 9 percent

Si. Thirty-one grades contain 10 to 13 percent Si, and 11 grades contain 16 to 23 percent Si. Copper ranges from 0.03 to 0.90 percent in 43 grades, from 1.0 to 2.0 percent in 23 grades and from 2.5 to 5.0 percent in 46 grades. In these alloys, the silicon improves castability and reduces hot shortness, and the copper increases strength.

There are 49 casting grades (3xx.0) and 63 ingot grades (3xx.1 and 3xx.2). Among the 112 grades, there are 68 original alloys (305.0, 319.1, 332.0, etc.) and 44 modified alloys (A305.0, B319.1, C355.2, etc.).

The following aluminum-silicon-copper alloys are typical workpiece materials for automotive and aerospace components.

- The 319.0 grade (6.0 percent Si and 3.5 percent Cu) is used for making automotive cylinder heads, internal combustion-engine crankcases and other parts that require pressure tightness and moderate strength.
- The 336.0 grade (12.0 percent Si, 1.0 percent Cu, 2.5 percent Ni and 1.0 percent Mg) is used for making automotive and diesel pistons, pulleys, sheaves and other components where high-temperature strength, a low coefficient of thermal expansion and good wear resistance are required.
- The 356.0 and A356.0 grades (7.0

Table 1: Typical mechanical properties of alloy 201.0.

Temper	Tensile strength, psi	Yield strength, psi	Shear strength, psi	Brinell hardness at 500 kg load
T4	53,000	31,000	Data is not available	95
T7	67,000	60,000	Data is not available	130
T6	70,000	63,000	42,000	135

Table 2: Typical mechanical properties of alloy 296.0.

Temper	Tensile strength, psi	Yield strength, psi	Shear strength, psi	Brinell hardness at 500 kg load
T4	37,000	19,000	30,000	75
T61	39,000	20,000	30,000	80
T6	40,000	26,000	32,000	90

Table 3: Typical mechanical properties of alloy 356.0 (permanent mold castings).

Temper	Tensile strength, psi	Yield strength, psi	Shear strength, psi	Brinell hardness at 500 kg load
T6	38,000	27,000	30,000	80
T7	32,000	24,000	25,000	70

Table 4: Mechanical properties of alloys 390.0 and A390.0 (sand castings).

Temper	Tensile strength, psi	Yield strength, psi	Fatigue strength, psi (at 5×10^8 cycles)	Brinell hardness at 500 kg load
F, T5	26,000	26,000	Data is not available	100
T7	36,000	36,000	Data is not available	115
T6	40,000	40,000	15,000	140

Table 5: Mechanical properties of alloys 390.0 and A390.0 (permanent mold castings.)

Temper	Tensile strength, psi	Yield strength, psi	Fatigue strength, psi (at 5×10^8 cycles)	Brinell hardness at 500 kg load
F, T5	29,000	29,000	Data is not available	110
T7	38,000	38,000	14,500	120
T6	45,000	45,000	17,000	145

percent Si and 0.3 percent Mg) are used for making automotive transmission cases, aircraft pump parts, aircraft fittings, water-cooled cylinder blocks and other parts that require pressure tightness and good corrosion resistance.

■ The 390.0 and A390.0 grades (17.0 percent Si, 4.5 percent Cu and 0.6 percent Mg) are used for making automotive cylinder blocks; four-cycle, air-cooled engines; pumps requiring abrasive resistance; brake shoes; and other parts that require high wear resistance, a low coefficient of thermal expansion and elevated-temperature strength.

Typical mechanical properties of 356.0 and 390.0 aluminum alloys are shown in Tables 3, 4 and 5. Solution heat-treated temper T6 produces higher strength and hardness in the 356.0 alloy (Table 3). Solution heat-treated temper T6 produces higher tensile, yield and fatigue strengths, as well as hardness, in the 390.0 alloy (Tables 4 and 5).

Aluminum-Silicon Alloys

Aluminum-silicon alloys are important commercial products primarily because of their superior casting characteristics, especially their high corrsion resistance. There are nine casting grades (4xx.0) and 12 ingot grades (4xx.1 and 4xx.2). Among the 21 grades, there are seven original alloys (413.0, 413.2, 443.0, 443.1, etc.) and 14 modified alloys (A413.0, B413.1, C443.0, C443.1, etc.).

The silicon content in these alloys is from 5 to 13 percent. Grades with less than 12 percent Si are hypoeutectic alloys, and the majority of those alloys contain 5 to 7 percent Si. Grades with close to 12 percent Si are eutectic alloys, such as the 411.2 alloy with 10 to 12 percent Si. There are seven variations of the 413.x alloy: sand castings, die castings, permanent mold castings, ingots, original grades and A and B modifications with 11 to 13 percent Si. Grades containing more than 12.6 percent Si are hypereutectic alloys.

Aluminum-silicon alloys are among the standard, general-purpose aluminum casting products. Alloys such as 443.0 (original), A443.0, B443.0 and C443.0 (modified) are used for making marine fittings, food-handling equipment and

Table 6: Aluminum alloy A390.0-T7: hardness 120 HB, tensile strength 38,000 psi.

Facemilling	Calculations performed by:		
	New method	"Handbook"	CTM
Cutting speed, sfm	3,600*	n/a	1,935
Spindle speed, rpm	4,584	n/a	2,465
Feed rate, ipm	115	n/a	62
MRR, in.^{3}/min.	34.5	34.5	18.5
Specific power, (hp/in.^{3}/min.)	n/a	0.32	n/a
Tangential cutting force, lbs.	35	n/a	n/a
Required machining power, hp	4.2	11.0	8.6
Required torque, ft.-lbs.	4.4	n/a	18.0

* Recommended value

Facemilling case study

HYPEREUTECTIC ALUMINUM ALLOYS are difficult-to-machine materials, and the 390.0 alloy with 17 percent Si is one of them. An amount of silicon in excess of 12 percent precipitates out of the aluminum matrix in the form of solid particles. These hard and abrasive particles make hypereutectic aluminum alloys highly resistant to wear and heat, which explains why these alloys are widely used for making cylinder blocks, pistons and other parts where excellent wear and high-temperature resistance are required.

Milling of the 390.0 alloy can be performed using C-2 and C-3 cemented carbides or PCD. Milling with cemented carbides is limited to relatively slow cutting speeds (325 to 575 sfm) to ensure adequate tool life. On the other hand, PCD tools provide significantly longer tool life. According to Kennametal Inc., Latrobe, Pa., milling of hypereutectic aluminum alloys can be done at cutting speeds from 3,000 to 12,000 sfm and feeds from 0.004 to 0.010 ipt when PCD tools are applied.

Osny Fabricio, Kennametal's global product manager for indexable milling and facemilling, said PCD tools are the right choice for facemilling of the 390.0 cast aluminum alloy at appropriate machining parameters. He provided the following information based on the 0°/90° facemill—Fix-Perfect and BGHX indexable inserts tipped with KD1410 PCD.

Tool diameter (D): 3.0"

Number of inserts (Z): 5

Machining parameters for roughing:

Cutting speed (V_c): 3,300 to 3,600 sfm

DOC: 0.150"

WOC (W): 2.0"

Feed rate (f_z): 0.003 to 0.005 ipt

Based on the above data, the author performed the following routine calculations.

Spindle speed at 3,600 sfm:

$n = 12 \times V_c \div (\pi \times D) = 12 \times 3{,}600 \div (\pi \times 3) = 4{,}584$ rpm

Feed rate at 0.005 ipt:

$F = f_z \times Z \times n = 0.005 \times 5 \times 4{,}584 = 115$ ipm

Metal-removal rate:

$Q = DOC \times W \times F = 0.150 \times 2 \times 115 = 34.5$ in.^{3}/min.

The required machining power can be calculated through the tangential cutting force and the cutting speed. The author developed formulas, described in his book "Engineering Formulas for Metalcutting," for the tangential cutting force calculation through the ultimate tensile strength of the workpiece material and the cross-sectional area of uncut chip. This method is more accurate than the required machining power calculations provided by "Machining Data Handbook" and cutting tool manufacturers.

All necessary step-by-step calculations of the tangential force, torque and required machining power are omitted, and the results are shown in Table 6.

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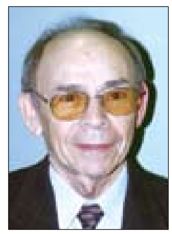
other applications that require excellent corrosion resistant, good pressure tightness and moderate strength.

A new calculation method shows the lowest required machining power and torque values at a much higher cutting speed, feed rate and metal-removal rate (Table 6). Respective values are based on "Machining Data Handbook" ("Handbook" for short) and the calculator developed by one of the major cutting tool manufacturers (abbreviated CTM for short). These values are in Table 6 for comparison.

There are six cast aluminum alloy groups defined by the principal alloying element. The three groups described in this article—2xx.x, 3xx.x and 4xx.x series—contain 171 grades of cast aluminum alloys. Keeping in mind that each grade is produced to several tempers, and each temper is characterized by different mechanical properties, an enormous availability of grade-temper cast aluminum alloys exists.

By understanding the composition of cast aluminum alloys, end users can be more confident in selecting the appropriate grades and the cutting parameters to maximize machining productivity. CTE



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