Cast Metal Matrix Composites

Meeting The Needs Of The Precision Components Marketplace

The precision component marketplace produces high-value, engineered components designed to fulfill demanding needs: Lightweight, stiff components that can operate to demanding specifications under adverse conditions. In the semiconductor fabrication market, designers have scaled down circuit elements – now approaching the 0.18µ in size. The aerospace industry continues to specify lighter and thinner parts for critical targeting and electronics assemblies. These requirements place high demands on fabrication equipment and on the materials chosen to perform the task. When automated machinery moves silicon wafers, or an imaging platform must be mounted on a helicopter, precise placement of components is critical. All of the moving parts of the device must be able to move and stop within exacting tolerances. At the same time, these machine elements must move rapidly to increase production throughput or react to a pilot's commands. Traditional materials like steel or aluminum force a compromise – either sacrifice precision of movement or location for higher speed, or reduce speeds to meet the precision positioning needed.

The goals of the precision components market require a demanding combination of material attributes:

- High specific stiffness (ratio of Young's Modulus to density)
- Dimensional stability
- Low coefficient of thermal expansion (CTE)
- High thermal conductivity
- Good damping characteristics
- Excellent wear properties
- Flexibility in design attributes & ease of manufacture

Cast metal matrix composite (MMC) materials satisfy these needs; they are reinforced metals, combining the features of metallic materials and ceramics. An aluminum alloy composite, like Duralcan's F3S.30S material, is reinforced with 30% silicon carbide particles. The material is readily melted and cast into complex geometries, meeting the requirements of machine designers with minimal post-cast processing to produce finished components.

Figure 1. Countergravity casting of MMCs at Hitchiner's Nonferrous Division, O'Fallon, Missouri.

Material Properties

The matrix of the Duralcan MMC alloy is an aluminum-silicon alloy, similar to A356. The similarities end there. The ceramic reinforcement phase, 20 or 30% silicon carbide (SiC) by volume, augments the properties that component designers need.

When designing moving components, weight and stiffness are considered. A pick-and-place fixture, for example, is required to move rapidly from location to location. As tolerances shrink, the component must be able to stop quickly at the new location and exhibit minimal flexural movement. The ratio of elastic modulus to the density of a material comprises its *specific stiffness*. Steel, for example, has a relatively high modulus, but the density is about three times that of aluminum. This enables a stiff assembly, but the high density carries with it high inertia that will impact movement and adds undesirable weight. Aluminum suffers the opposite problem – the lightweight machine elements can move rapidly, but the low stiffness precludes precision location of an assembly. In practice, most preci-

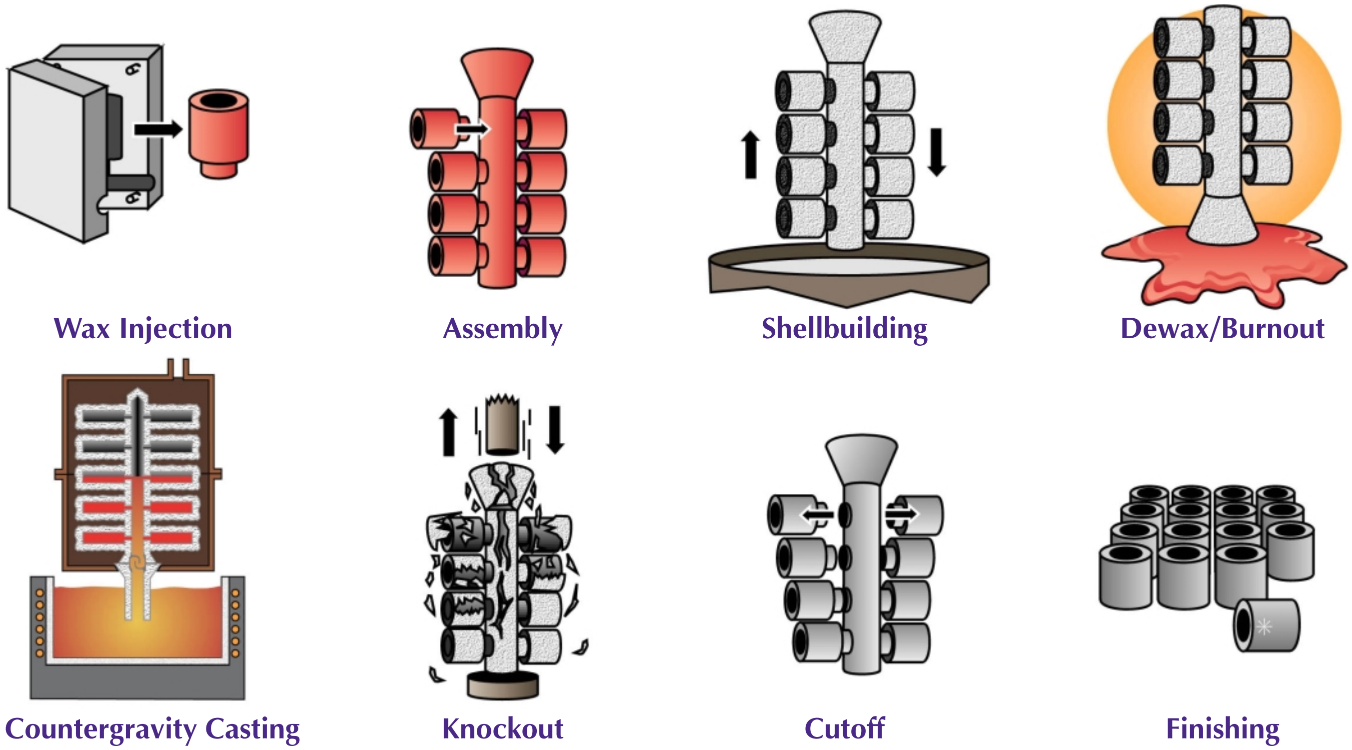

Figure 2. Basic steps in the investment casting process for MMCs using Hitchiner's exclusive Countergravity technique.

sion component designs become limited by stiffness issues. A highly-utilized alloy like A356 aluminum will cover the tensile properties such as ultimate strength and yield point easily, but will fall far short of the stiffness requirements of aerospace or commercial precision assemblies. In applications where A356 will meet requirements, the cost of cast composites precludes their selection – these materials clearly cover different types of application, and should not be considered interchangeable.

Integrating components that are made from dissimilar materials can demand dimensional stability and low thermal expansion. This is a critical limitation of traditional aluminum alloys when incorporated into optical targeting systems, for example. Optical systems typically employ many different materials, and differences in thermal expansion can lead to unacceptable inaccuracies during operation. Aluminum alloys display high thermal expansion coefficients. Thermal conductivity is also needed, and while aluminum is conductive, steel conducts heat poorly.

The Duralcan F3S.20S (20% SiC) & F3S.30S (30% SiC) materials combine high specific stiffness with a low CTE and high thermal conductivity. Table 1 compares these materials to traditional engineering alloys.

The Duralcan composites combine these desirable features with manufacturing flexibility; the materials can be cast by nearly all commercially available processes. Selecting a premium quality casting process, like the Counter Gravity Casting process available from Hitchiner Manufacturing, can leverage this flexibility. MMC casting operations at Hitchiner are located at the Nonferrous Division, O'Fallon, MO (Figure 1). Duralcan's material certifications enable Hitchiner to confidently offer these materials to meet the stringent requirements of the aerospace community as well.

Hitchiner Manufacturing & MMC The Counter Gravity Advantage

MMC materials are thixotropic in nature. Entraining air into the molten alloy during stirring can ruin an MMC melt. This consideration extends to filling the mold; MMC materials with high-particle loadings – the loadings needed for high precision applications – must enter a mold cavity in the least turbulent manner possible. Ladle pouring of the material, common to sand, permanent mold, and conventional investment casting, can easily introduce turbulent flow as the metal plunges from the ladle into the

Table 1. Property Comparison For Duralcan MMC & Traditional Engineering Alloys

(All values are room temperature properties)

Material Property	Units	A356 Al - T6	Class 30 Gray Iron	Duralcan F3S.20S	Duralcan F3S.30S
Matrix	Vol %	—	—	359Al–80%	359Al–70%
Reinforcement	Vol %	—	—	20% SiC	30% SiC
Elastic Modulus	MSI	10.5	14.7	14.3	17.4
	GPa	72	101	99	120
Density	lb/in^3	0.0970	0.2580	0.0989	0.1011
	g/cm^3	2.69	7.14	2.74	2.80
Specific Stiffness	in x 10^9	108.2	57.0	144.6	172.1
	GPa-cm^3/g	26.7	14.1	36.1	42.9
Mean CTE (to 212°F)	ppm/°F	11.9	5.6	9.7	8.1
(to 100°C)	ppm/°C	21.4	10.1	17.5	14.6
Thermal Conductivity	BTU/ft-hr-°F	88.0	26.5	107	83.5
	W/m-°C	152	46	185	145
Specific Heat	BTU/lb-°F	0.21	0.12	0.20	0.19
	J/kg-°K	900	502	837	795
Tensile UTS	KSI	38	30	52	31.4
	MPa	262	207	359	216
Tensile YS (0.2%)	KSI	27	N/A	44	30.5
	MPA	186	N/A	303	210
Tensile Elongation	%	5.0	N/A	0.4	1.0

Notes: Duralcan 20S values are for "T6" temper, 30S values are for "F" temper

gating system's downsprue. In addition, the cold molds used in sand and permanent mold casting exacerbate the effects of turbulence by trapping gas bubbles in the rapidly solidifying metal.

The Hitchiner Countergravity investment casting process, originally developed in the mid-1970s, uses vacuum to provide the driving force to fill the casting. Hitchiner is a world leader in the production of premium quality investment castings.

Figure 2 shows the basic investment casting process used at Hitchiner. In the casting step, a hot mold is placed in a vacuum chamber with a fill pipe extending out the bottom. The fill pipe entrance is lowered beneath the surface of the molten metal, and a vacuum is applied to the casting chamber. Atmospheric pressure on the melt forces the metal to rise up the fill pipe and enter the mold. By tailoring the vacuum profile to the casting geometry and alloy, the result is metal drawn from the clean, undisturbed zone under the melt surface, filling the cavity in a quiescent manner. A hot mold near the solidus temperature for the material helps achieve fine cell sizes.

Hitchiner's counter gravity casting process enables our team to provide premium quality cast composites in geometries of great complexity. This allows a customer the freedom to implement design features once reserved for fabrications. Figure 3 shows a one piece MMC casting made

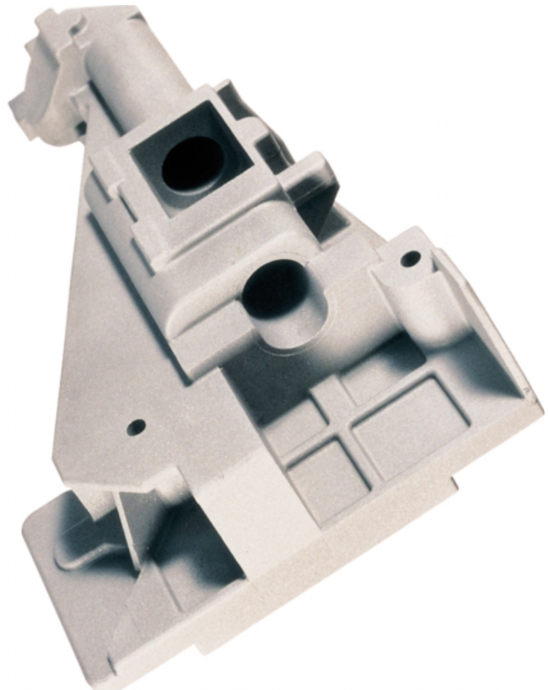

Figure 3. A 30 to 40% silicon carbide metal matrix aluminum alloy part made for an application requiring high heat transfer and high stiffness with lightweight.

by Hitchiner. The near-net-shape technology of investment casting also allows for lower costs by reducing post-cast grinding and machining operations – especially important for difficult to machine materials such as MMCs. Hitchiner's position as a world-class supplier of investment castings extends to its leadership position supplying high-quality cast composites to the semiconductor and precision component industries. Hitchiner currently generates approximately $3 million in sales per year in cast MMC components, and is currently expanding capacity to meet the future needs of its customers.

Conclusions

The demand for precision components in the semiconductor, electronics, and aerospace industry is increasing. Tool designers are routinely constrained by the limited mix of material properties in traditional alloy systems. The compromises imposed by this reality reduce the competitiveness of a manufacturer in the marketplace by forcing trade-offs between throughput and precision.

Metal matrix composites offer a solution; the benefits of a unique mix of material properties and established infrastructure of alloy suppliers, manufacturers, and machining centers to process parts. Suppliers of premium quality cast parts, like Hitchiner Manufacturing with its counter gravity casting process, provide an essential and reliable link in this supply chain.

Designers can rely on the experience and knowledge of a world-class supplier like Hitchiner Manufacturing to provide the means to produce demanding components. The enabling features of cast composites, combined with Hitchiner's counter gravity casting process, will help designers meet the goals of the precision component marketplace, now and in the future.

HITCHINER MANUFACTURING CO., INC.

Ferrous Division/Gas Turbine Division
P.O. Box 2001
Elm Street
Milford, NH 03055
Tel: (603) 673-1100

Nonferrous Division
P.O. Box 280
600 Cannonball Lane
O'Fallon, MO 63366
Tel: (636) 272-6176

Hitchiner–France
15, rue du Général Leclerc
F78000 Versailles, France
Tel: 01-39-20-07-31

Hitchiner S.A. de C.V.
Cruce de las Carreteras
Tenango-Marquesa y Tianguistenco Chalma S/N
Santiago Tianguistenco, Estado de Mexico
Tel: (713) 3-62-83

Tooling Division
7 Northern Boulevard
Amherst, NH 03031

Metal Casting Technology, Inc.
127 Old Wilton Road
Milford, NH 03055

http://www.hitchiner.com/