ALUMINUM POWDER METALLURGY

Increased demand for light weight components, primarily driven by the need to reduce energy consumption in a variety of societal and structural components, has led to increased use of aluminum. Additionally, the cost of fabrication coupled with a need to improve part recovery has led to significant growth in the net-shaped component manufacturing processes.

Aluminum Powder Metallurgy (P/M) offers components with exceptional mechanical and fatigue properties, low density, corrosion resistance, high thermal and electrical conductivity, excellent machinability, good response to a variety of finishing processes, and which are competitive on a cost per unit volume basis. In addition, aluminum P/M parts can be further processed to eliminate porosity and improve bonding yielding properties that compare favorably to those of conventional wrought aluminum products.

The primary driver for the use of aluminum P/M is the unique properties of aluminum coupled with the ability to produce complex net or near net shape parts which can reduce or eliminate the operational and capital costs associated with intricate machining operations. Aluminum P/M can replace other P/M in certain applications on a direct basis. However, in terms of the potential for ferrous based product substitution, each potential application needs to be considered on a case by case basis. Typical economics tend to favor iron parts but the unique characteristics of aluminum such as strength, weight, corrosion resistance, and machinability can make the aluminum parts economically viable.

POWDER METALLURGY

Powder Metallurgy is a highly evolved method of manufacturing reliable net shaped components by blending elemental or pre-alloyed powders together, compacting this blend in a die, and sintering or heating the pressed part in a controlled atmosphere furnace to bond the particles metallurgically. The P/M process is a unique part fabrication method that is highly cost effective in producing simple or complex parts at, or close to, final dimensions. P/M processing provides the following advantages:

- Production of complex shapes to very close dimensional tolerances, with minimum scrap loss and fewer secondary machining operations.
- Physical and mechanical properties of components can be tailored through close control of starting materials and process parameters.
- Particular properties can be improved through secondary processing operations such as heat treating and cold/hot forming.

ALUMINUM POWDER METALLURGY

The aluminum P/M process consists of three basic steps.

1. Aluminum powders of controlled purity and particle size are mixed with alloying metal powders in precisely controlled quantities. Generally a powdered lubricant is added to permit the consistent production of high density parts without seizing of

the punches or cold welding to the die walls. This lubricant is carefully chosen to ensure that there is no residual ash to interfere with bonding during sintering.

2. The premix is compacted using precision metal dies in specially designed P/M presses to yield a green compact. Aluminum premixes exhibit excellent compressibility and yield high density parts at low compaction and ejection pressures. Premixes can be compacted to 90% density at only 12 tsi and 95% at 25 tsi. Typical green strengths range from 450 to 1500 psi which is sufficiently strong to withstand normal handling without chipping or breaking.

3. The green compacts are sintered in a controlled atmosphere furnace at closely regulated temperatures. This process metallurgically bonds the powder particles together and develops the desired physical and mechanical properties. Aluminum powder sintering is difficult to achieve because the aluminum oxide is not reduced by common furnace atmospheres at sintering temperatures. However, successful sintering is accomplished in environments containing hydrogen, nitrogen and dissociated ammonia as long as the following conditions are observed:

   - The lubricant is essentially free of moisture and low in ash contact.
   - Atmospheres contain low levels of moisture and oxidizing gases.
   - Alloying elements having a high solubility in aluminum are added to generate low melting phases.

Most aluminum P/M alloys are sintered between 1000 and 1200°F with a sintering time of 7 to 20 minutes. The recommended atmosphere is nitrogen with a furnace dew point range of -40 to -60°F. Higher dew points yield reduced properties and very high dew points can result in gross expansion of the compact.

TYPICAL ALUMINUM P/M BLEND CHEMISTRIES (percent)					
Alloy	**Cu**	**Mg**	**Si**	**Al**	**Lubrication**
A	0.25	1.0	0.6	Bal.	1.5
B	4.4	0.5	0.6	Bal.	1.5
C	-	0.6	0.4	Bal.	1.5
D	4.0	-	-	Bal.	1.5
E	2.0	1.0	0.3	Bal.	1.5
F	1.6	2.5	-	Bal.	1.5
G	3.8	1.0	0.75	Bal.	1.5

PERFORMANCE PROPERTIES OF ALUMINUM P/M COMPONENTS

Aluminum P/M parts can be produced with a range of properties. **Mechanical** properties can vary from 16 ksi to 50 ksi depending upon composition, density, sintering practices and thermal treatments. Further secondary processing such as hot or cold forming can yield properties approaching those of conventional wrought aluminum materials.

Aluminum P/M mechanical properties are very good and typically dominate in the materials selection process. For certain applications, the dynamic properties as well as other performance properties are more critical and become the determinant criteria. These properties typically include, but are not limited to, fatigue, density, electrical and thermal conductivity, corrosion resistance and machinability.

Fatigue is an important decision consideration for P/M parts subject to dynamic stresses. The most commonly used fatigue property is the fatigue limit, which is the maximum reversed stress the material will withstand if cycled indefinitely. This limit is defined when the fatigue curve becomes horizontal. For ferrous materials this limit is at 10 million cycles while for aluminum alloys it is at 500 million cycles. Fatigues limits for 2xxx and 6xxx aluminum P/M alloys are 7.5 and 6.5 ksi, respectively, and are about 50% of the comparable wrought alloys. This difference is due to the lower density of P/M parts. Hot forging the aluminum P/M part results in fatigue limits comparable to the wrought alloys.

A distinguishing characteristic of P/M aluminum is its **lighter weight** in comparison to other common P/M materials. <u>Aluminum enjoys better than a 3 to 1 weight advantage over iron, nickel and copper</u>. Another benefit of aluminum is its excellent **conductivity**, both electrical and thermal, in comparison to most other metals. Aluminum P/M parts are comparable to their wrought counterparts and can be utilized as heat sinks or electrical conductors.

MECHANICAL PROPERTIES OF SELECTED ALUMINUM P/M ALLOYS

Alloy	Temper	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation %	Compressive Yield Strength (ksi)	Ultimate Shear Strength (ksi)	Modulus of Elasticity (psi X 106)
A	T-1	20.1	12.7	5.0	-	-	-
	T-4	24.9	16.6	5.0	25.3	19.0	8.8
	T-6	33.6	32.5	2.0	25.4	20.1	8.1
B	T-1	29.2	24.6	3.0	-	-	-
	T-4	35.6	29.8	3.5	26.0	29.0	8.8
	T-6	46.8	46.7	0.5	29.7	26.0	8.3
E	T-6	38.0	29.0	3.0	-	-	-
F	T-6	45.0	40.0	2.0	-	-	-

All at approximately 90% theoretical density

T-1 - As sintered

T-4 - Heat treated, cold water quenched and aged (minimum of four days at room temperature)

T-6 - Heat treated, cold water quenched and artificially aged

Aluminum alloys enjoy widespread use in both structural and non structural applications because of their **corrosion resistance**. Within the aluminum alloy systems, some compositions are more resistant than others. The Al-Mg-Si alloys (6xxx series) exhibit higher resistance to general corrosion than the Al-Cu (2xxx series) but all are significantly better than ferrous based products. The corrosion resistance of aluminum P/M alloys can be improved appreciably through application of chemical conversion coating on anodizing treatments.

Aluminum P/M parts offer many of the important advantages of wrought aluminum in **machining** operations, including high cutting spreads, smooth surface finish and outstanding tool life. In lathe turning tests, 90% density test bars from both 2xxx and 6xxx P/M alloys were machined to a fine surface finish with small, broken chips at a cutting spread of 500 sfm. The P/M version actually offers an advantage since wrought aluminum can yield long stringy chips that often necessitate a reduction in machining speeds.

Sintered aluminum parts can be given a variety of **surface finishes**. These include chemical cleaning, mechanical finishing and etching to achieve textures, coloring for decorative or functional purposes, electroplating and painting. Aluminum P/M parts may be chromate conversion coated or anodized for increased resistance to corrosion. Hard type anodize finishes can be applied for additional wear resistance.

ALUMINUM COMPARISON TO OTHER P/M MATERIALS

A direct comparison of mechanical properties of aluminum P/M with ferrous based products reveals that, like its wrought aluminum counterpart, has lower, but competitive, strength levels. However, there are many major property advantages associated with aluminum P/M alloys.

A major advantage is the **density** of aluminum which is translatable into many property, processing and economic benefits. Parts will weigh less and relatively small changes in part dimensions can yield bulk properties comparable to the ferrous based parts while still maintaining an overall weight advantage. This is a major benefit in today's energy conscious world. In addition, because of the lower density, the relatively high cost per pound of aluminum P/M raw materials becomes less significant and more competitive with typical P/M materials, when considered on a cost per unit volume or individual part weight basis. This lighter weight can also be translated into a potentially higher volume of parts per inch of belt in the sintering operation (i.e., greater productivity), and also lowers shipping costs.

Other significant property advantages associated with aluminum P/M include **corrosion resistance, conductivity and finishing characteristics**. The excellent corrosion resistance of aluminum alloys has been well established through years of experience in marine, aerospace and chemical industry applications. In normal outdoor exposure aluminum P/M alloys will provide corrosion resistance equivalent to brass, bronze and stainless steel P/M parts and significantly better than ferrous based products. This corrosion resistance also means that no special coatings are necessary for normal shipping and storage. Aluminum has excellent conductivity values, both thermal and electrical. Aluminum P/M is comparable to it's wrought counterparts and significantly better than brass, bronze and ferrous based materials. The natural appearance of aluminum P/M parts after chemical or mechanical cleaning is suitable for most applications where good appearance is a requirement. In addition, a wide range of decorative and functional finishes are available with aluminum P/M that are not possible with other P/M materials.

COMPARISON PERFORMANCE OF SELECTED ALUMINUM P/M ALLOYS IN HIGH HUMIDITY AND 5% CONTINUOUS SALT SPRAY TESTS

Alloy	Temper	Relative Corrosion Rating	Specimen Appearance
Alloy A (low Cu)	T-1	B	Moderate attack, scattered pits; some large
	T-4	A	Slight attack; scattered small pits
	T-6	A	Slight attack; scattered small pits
Alloy B (high Cu)	T-1	D	Heavy attack; many large sites
	T-4	C	General attack; scattered large sites
	T-6	C	General attack; scattered large sites
6061 (wrought)	T-6	A	Slight attack; few small pits
2014 (wrought)	T-6	C	General attack, scattered large sites
Fe-2Ni-0.5C	As-sintered	E	Severe attack; complete surface erosion

T-1 - As sintered
T-4 - Heat treated, cold water quenched and aged (minimum of four days at room temperature)
T-6 - Heat treated, cold water quenched and artificially aged
Testing performed according to ASTM B 117-64

Aluminum P/M also offers **economic advantages** in the parts fabrication area. These blends exhibit excellent compressibility and yield high density parts at low compaction and ejection pressures. Aluminum P/M blends can be compacted to 90% theoretical density at only 12 tsi and 95% at 25 tsi which is much lower than comparable ferrous based materials. These lower pressures permit the use of smaller, faster presses to produce larger parts and, in some cases allows the use of multiple cavity tooling. Lower compaction pressures reduce the possibility of damage in fragile tool designs and tool breakage is less likely with aluminum. Sintering temperatures for aluminum P/M parts are much lower (1100°-1200°F) than other P/M parts (>2000°F). This yields significant energy savings in the production process. The sintering atmosphere gases for aluminum part production also tends to be more economical. The atmosphere of choice for aluminum tends to be low dew point nitrogen while other P/M parts use a combination of hydrogen (5-15%) and nitrogen. Since hydrogen gas is 3-4x more expensive than nitrogen, the use of nitrogen alone can translate into further cost savings.

Aluminum P/M parts offer many advantages over other P/M products. In addition to properties such as low density, thermal and electrical conductivity, finishing characteristics and corrosion resistance not available with other P/M products, aluminum can be economically viable on a direct part replacement basis. An analysis of a hypothetical P/M flange part with a flange diameter of 1 inch and the length of 0.06 inches coupled with an overall length and body OD of 0.75 inches suggests a 30% lower cost than 316L SS, a 20% lower cost than Bronze 90-10 and a comparable cost with FC0008 at a density of 6.6.

ALUMINUM P/M PRODUCERS

For additional information on aluminum P/M, you can contact the following domestic producers:

Alcoa Specialty Metals Division, New Kensington, PA
contact David Hyland, Vice President of Sales and Marketing at 724-339-6721
Ampal Inc., Palmerton, PA
contact Frank Beaumont, Vice President & General Manager at 610-826-7020
Toyal America Inc., Naperville, IL
contact Bud Loprest, Sales & Marketing Manager at 630-505-2169

This brochure was prepared by members of the Marketing and the Technical & Standards Committees of the Pigments and Powder Division of The Aluminum Association, Inc.