DATA SHEET

AlBeMet® Technical Fact Sheet

Description

Aluminum-beryllium metal matrix composites combine the high modulus and low-density characteristics of beryllium with the fabrication and mechanical property behavior of aluminum. Aluminum beryllium metal matrix composites offer excellent specific stiffness and processing characteristics. This makes it more suitable for cost sensitive markets such as semi-conductor assembly and inspection equipment, avionics, and satellite electronics.

These metal matrix composites are weldable, and can be formed, machined, and brazed like conventional aluminum metal matrix composites. Aluminum beryllium metal matrix composites do not display sensitivity to machining damage and do not require etching after machining like beryllium. As aerospace systems become more weight sensitive, complex, and cost sensitive, these metal matrix composites provide benefits in many applications. When compared to metal matrix and organic composites, aluminum beryllium metal matrix composites are simpler to use and easier to fabricate.

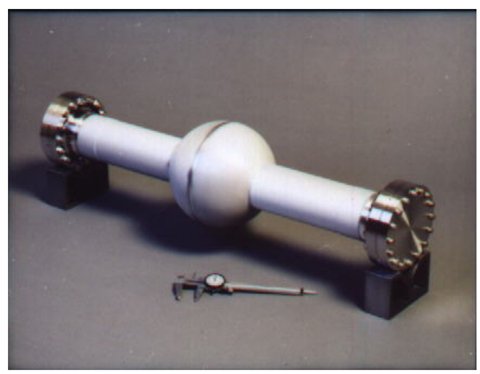
What is AlBeMet®?

AlBeMet® is a family of metal matrix composites made up principally of beryllium and aluminum. The ratio of the two metals can be varied to alter the physical, thermal and mechanical properties.

AlBeMet® AM162-AlBeMet® AM162 contains 62 wt% commercially pure beryllium and 38 wt% commercially pure aluminum.

AlBeMet® Offers:

- High Thermal Conductivity
- Light Weight
- High Specific Stiffness
- Thermal Stability
- Mechanical Properties with a high degree of isotropy
- Manufactured by conventional powder metallurgy while being able to be fabricated with conventional aluminum technology



What are the advantages to using AlBeMet®?

Beryllium, when alloyed with aluminum to form a metal matrix composite, produces a unique combination of high specific modulus of elasticity, low density and high heat capacity in comparison to all common structural materials. Historically, beryllium-based materials have been applied in air and spaceborne structures, which require their low density and high elastic modulus. Today, beryllium thermal management capabilities for airborne electronics have become as important as structural efficiency. In addition, aluminum-beryllium metal matrix composites have made significant inroads into components for high-performance engines and brakes.

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Products, Uses and Descriptions

	AlBeMet® 162
Form	• Rolled Sheet • Hot Isostatically Pressed Bar • Extruded Bar • Net Shapes
Avionics	• Minimizes stress from vibration on leads • solder joints and substrates • Increases fatigue life of electronic packages • Reduced section thickness • Design flexibility • Heatsinks, dip-brazed chassis
Optical Structures	• Higher first mode frequencies • Improved Line-Of-Sight (LOS) jitter • Simpler design, more room inside housing • IFTS, Apache, SPIRITT, JSF, F18, FLIR, ATP, Damocles
Satellite Structures	• Faster designs versus composites • Lighter, stiffer, thermally-stable versus aluminum • Flying on 150 satellites • Not susceptible to Stress Corrosion Cracking

Avionics Systems. Avionics systems require weight reduction, while needing to increase the first mode frequency of the system. AlBeMet® 162 with a density of 2.1 g/cm^3 (0.076 Lb/in^3), combined with an elastic modulus of 193 GPa (28 Msi), provides a unique combination of physical properties and specific stiffness (E/ρ) that is four times higher than structural alloys of aluminum, magnesium, titanium and stainless steels.

Optical Structures. Designers seeking improved performance are looking beyond the capabilities of aluminum and other more common materials. In many cases, they are finding unmanageable costs or unattractive tradeoffs. Only aluminum-beryllium gives them the combination of properties that consistently meets their expectations. Provides a level of performance to reduce jitter and increase line of sight distance.

Satellite Structures. AlBeMet® provides properties that are roughly halfway between aluminum and beryllium and at the same time significantly reducing the cost of finished components. Reducing raw material and part fabrication costs attains this savings. Aluminum beryllium's performance to cost relationship has allowed Materion's customers to successfully use AlBeMet® as a replacement for traditional aluminum. A position rarely justified when comparing beryllium to aluminum.

Mechanical Properties

This material is produced by a gas atomization process, which yields a spherical powder with a fine beryllium structure. Three consolidation processes densify the powder each resulting in different mechanical properties, while maintaining AlBeMet's unique physical properties. The mechanical properties of AM162 have been extensively characterized in all three-product forms. But a significant design database has been developed for the extruded product form. The extruded bar is fabricated by Cold Isostatic

Pressing (CIPing) the isotropic spherical aluminum-beryllium powder into semi-dense billets and then canning the billet for subsequent extrusion. Mechanical properties are minimum values at room temperature. Wrought mechanical properties for extrusions are in the longitudinal direction. Transverse properties are generally lower. A number of standard extrusion dies are available. Rolled product is available in a thickness range of 0.063" to 0.313" x 25" (0.16 to 0.795 cm x 63.5 cm) length time's width dependent on gauge. Mechanical properties for HIP'd, extruded, and/or rolled AlBe metal matrix composites are in the annealed condition.

WHY USE ALBEMET®?

1. To replace steel and titanium in stiffness-critical applications and save weight
2. To maximize electronic's thermal performance and provide superior vibration damping which improves component life and reliability. AlBeMet®'s low mass and high stiffness reduce vibration
3. To maximize dimensional stability in optical systems to improve performance
4. To provide design flexibility when aluminum does not meet requirements
5. Cost Reduction
6. Weight Reduction
7. Surface Finish
8. Smooth Consistent Surface Finish
9. Design Benefits
10. Maximized Configuration Complexity
11. Dimensional Repeatability and Consistency
12. Distribution of Stress
13. Lower Maintenance
14. Custom orders of complex shapes produced to customer specifications
15. Design and engineering services available to help you handle your most complex jobs

PHYSICAL PROPERTIES

1. High modulus-to-density ratio, 4 times that of aluminum or steel, minimizes flexure and reduces the chance of mechanically induced failure.
2. Thermal conductivity of approximately 210 W/m·K exceeds by about 25% that of common aluminum metal matrix composites such as Al 6061.
3. The CTE of 13.9 ppm/C matches that of the ceramic chip carriers (alumina has CTE of ~8ppm/C) more closely than does aluminum, which has a CTE of 24ppm/C.
4. The stiffness and low density of AlBeMet® are beneficial in aircraft, where high loads generated during tight maneuvering can cause flexure of circuit boards, and subsequent mechanical failure.

FATIGUE PROPERTIES

Is Cyclic fatigue critical to the life cycle of your component? The fatigue properties of AlBeMet® extruded material have been tested using the R.R. Moore rotating beam fatigue test utilizing fully reversed cycles with a R= -1. The fatigue limit, 1×10^7 cycles was about 207 MPa (30Ksi) in the longitudinal direction and 165 MPa (25 Ksi) in the transverse direction. This property is approximately 75% of the minimum RT yield strength, which is two times that of typical fatigue properties of 6061T6 aluminum.

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Physical Properties of AlBeMet® Alloys Compared to Common Aluminum Alloys	2024T6	6061T6	AM162
Density g/cm^3 (Lbs/in^3)	2.77 (0.100)	2.70 (0.100)	2.10 (0.076)
Modulus GPa (Msi)	72 (10.5)	70 (10.0)	193 (28)
Poisson's Ratio	0.33	0.33	0.17
CTE @ 25°C ppm/°C (ppm/°F)	22.9 (12.7)	23.6 (13.1)	13.9 (7.7)
Thermal Conductivity @ W/m°K (BTU/hr Ft° F)	151 (87)	180 (104)	210 (121)
Specific Heat @ 20°C J/Kg°K (BTU/lb °F)	875 (0.209)	896 (0.214)	1465 (0.35)
Electrical Conductivity @ 20°C, % IACS	30	43	49
Damping Capacity 25°C, 500 HZ	1.05×10^{-2}	1.05×10^{-2}	1.5×10^{-3}
Fracture Toughness K_{Ic} Ksi √in (MPa √m)	23 (25)	23 (25)	10-21 (11-23)

A Comparison of AM162 AlBeMet® HIP'd, Extruded Bar, and Rolled Sheet

Property	HIP'd Billet	Extruded Bar	Rolled Sheet
Composition	Al-62 wt% Be	Al-62 wt% Be	Al-62 wt% Be
Density g/cm^3 (lb/in^3)	2.071 (0.0748)	2.071 (0.0748)	2.071 (0.0748)
Yield Strength MPa (Ksi)	193 (28)	276 (40)	276 (40)
Ultimate Strength MPa (Ksi)	262 (38)	400 (58)	386 (56)
Elongation %	2	7	5
Modulus GPa (Msi)	193 (28)	193 (28)	193 (28)
Thermal Conductivity at 25°C W/m·K (Btu/hr-ft-°F)	210 (121)	210 (121)	210 (121)
Coefficient of Thermal Expansion at 25°C ppm/°C (ppm/°F)	13.91 (7.73)	13.91 (7.73)	13.91 (7.73)

Tensile Yield Strength at Typical Room Temperature

Product	Heat Treat	Yield Strength MPa/Ksi	Ultimate Strength MPa/Ksi	Elongation %
HIP'd Billet	593°C/24 hour	221 (32)	188 (42)	4
Extruded Bar	593°C/24 hour	328 (48)	439 (64)	9
Rolled Sheet	593°C/24 hour	314 (46)	413 (60)	7

The room temperature tensile strength of the wrought forms of AM162 compares favorable to 6061T6 aluminum and are less than the 2024T6 aluminum.

Stress Corrosion Cracking

Materion's Beryllium Products and Composites and independent laboratories including the European Space Agency (ESTEC) materials lab have tested AlBeMet® 162 sheet and extruded products for stress corrosion. The testing consisted of using the ASTM G28-73 test procedure, C-ring Stress Corrosion Testing and subjecting the specimens to 30 days in a 2.5% sodium chloride (NaCl) solution. The results indicate that none of the specimens failed during the 30 days testing, and is subsequent tensile strength testing no degradation. ESTEC/ESA has given their approval for the use of AlBeMet® 162 for use on satellite structures for European Spacecraft.

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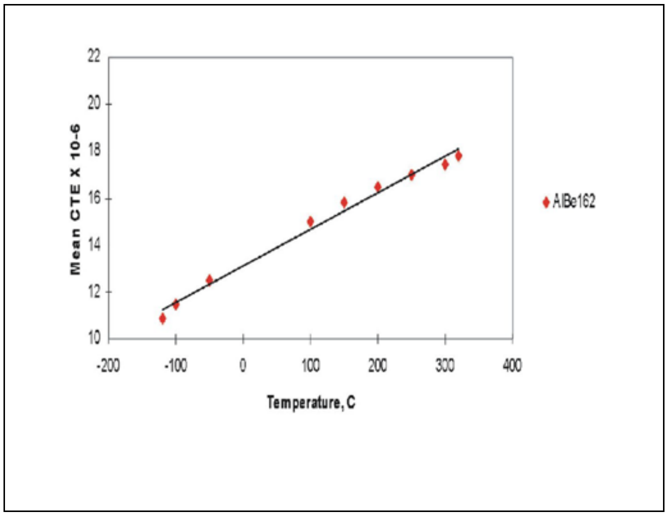
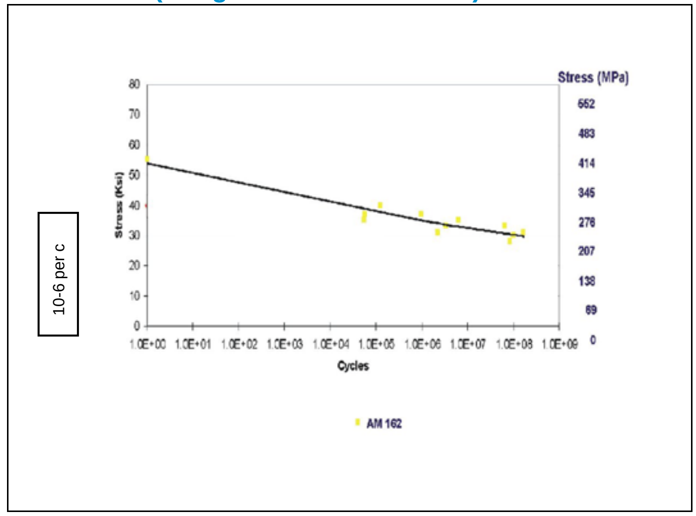
CTE



The graph depicts the Coefficient of Thermal Expansion for AlBe metal matrix composites.

FATIGUE (Longitudinal Orientation)



The AlBeMet® Fatigue-Extruded Heat Treated (593˚C-24 hr)

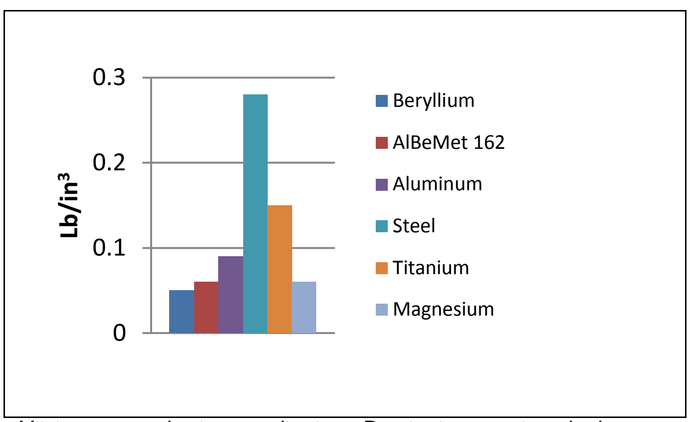
Thermal Properties

Most important fact in Surface Mount Technology (SMT) circuit board cores is coefficient of thermal expansion (CTE).The better the CTE match, the less strain imposed on solder joints. Less strain translates into better fatigue life for solder joints and longer life for the board. Thermal management capabilities, characterized by the thermal conductivity and heat capacity, have also been found to be important factors.

Formability

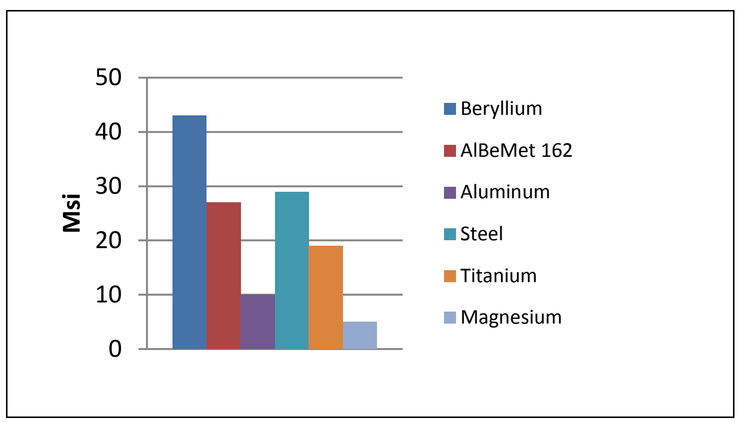
Forming the sheet material, is similar to aluminum, in that the same tooling and temperature ranges can usually be applied, but at a higher forming temperature, typically over 200˚C (392˚C). The forming rate is slightly slower for AlBeMet® materials. Testing includes modal identification testing, axial & lateral static loading conditions, anticipated axial and later vibration, shock loads, and thermal cycling loads random vibration testing. This chart depicts in minimum gage aluminum applications; density is approximately the same as fiberglass.

Density



Miinimum gage aluminum applications. Density is approximately the same as fiberglass. AlBeMet® can provide weight savings of 25%.

Modulus



Modulus (stiffness) of material being almost same as steel. In stiffness driven apps, AlBeMet® can provide 50% weight savings.

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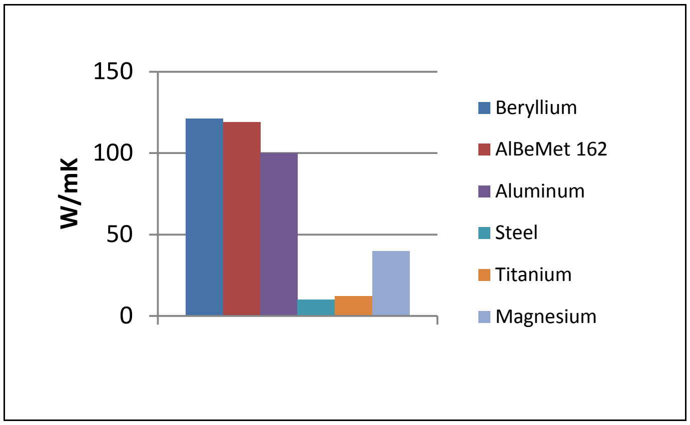
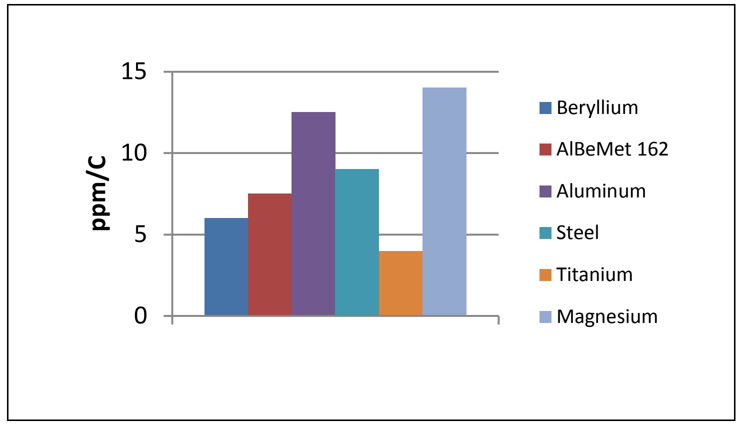
Thermal Conductivity



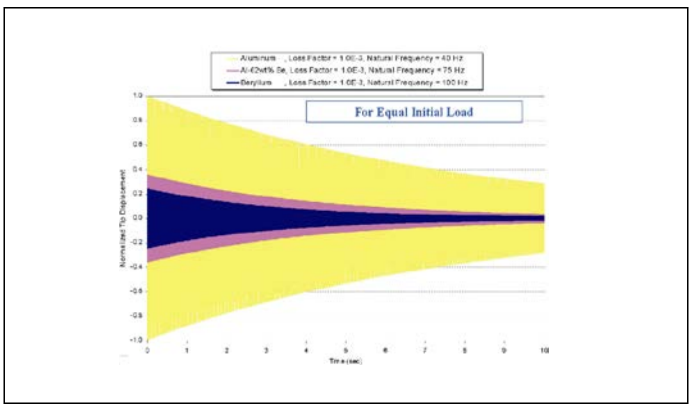
Thermal conductivity is excellent for dissipating heat from electronics. Using beryllium materials in heat sink cores has improved life of some electronic modules as much as 8 times.

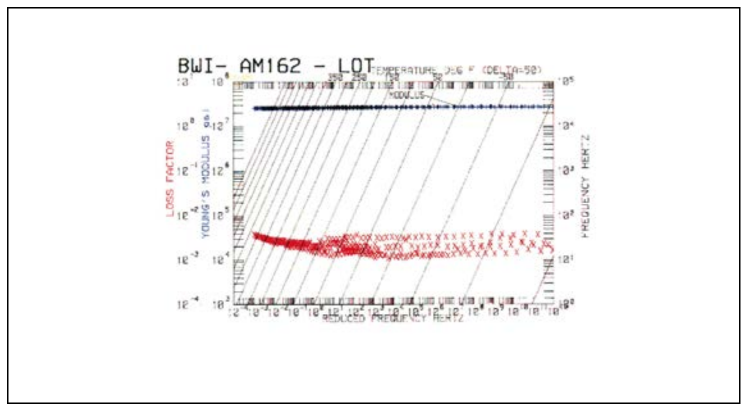
Coefficient of Thermal Expansion



CTE is nearly identical to circuit boards. Compatibility of CTEs reduces thermal strains between cores & circuitry components resulting in fewer failures. In an application the CTE of the base material is a dominant contribution to thermal mechanical stress.

Vibration Damping





Elastic modulus affects vibration decay of material with same damping capability.

Typical Values Joint Strength

AlBeMet® 162	Typical Joint Strength
Epoxy Bonding (Phenolic Epoxy BR 127 primer, Hysol High Strength Epoxy)	4000 psi (Shear)
Dip Brazing, 580˚C, Braze Alloy 718	14500 psi (Shear)
Fluxless Vacuum Brazing	10000 psi (Shear)
Tig Welding	30000 psi (Shear)
EB Welding	45000 psi (Shear)

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Extruding – a conventional approach to the creation of thick-walled aluminum beryllium tubes and shapes. Extrusion provides consistent mechanical properties, dimensions and tolerances.

Hot Isostatically Pressing – The specification identification (H) identifies the grade available by Hot Isostatic Pressing (HIP) AM162H. AM162H utilizes spherical atomized powder that is consolidated in a sheet metal that can be formed into the shape of the final part. The can is degassed, sealed and HIPed to conserve material (powder) to reduce the total finish machining time.

Semi-Solid Processing - This process enables the net shape and high production capability of permanent mold die casting for a material whose high melting point and reactivity preclude conventional die casting. The Semi-Solid machining process has been successfully adapted to the AlBeMet® alloy systems with beryllium contents lower than 30% using both 7075 and 6061 as the aluminum alloy matrix material. SSM properties match the rule of mixtures predictions based upon A356 (or 7075 or 6061) and beryllium. The SSM process is cost effective in large volume applications with complex three-dimensional shapes. SSM offers lower input material cost and lower machining cost to produce the final part. SSM allows for lower processing temperatures resulting in higher die life than conventional die casting techniques.

CORROSION RESISTANCE

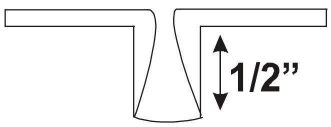
Beryllium is corrosion-resistant in air up to 600˚C. This is attributed to the formation of an adherent oxide layer on the surface. The volume, occupied by the oxide, is greater than the volume of the original metal consumed and forms an effective barrier to further oxidation. Beryllium shows similar corrosion resistance in water as it does in air. Below 600˚C, the oxide layer protects beryllium from attack. The presence of salts in water, particularly chloride, dramatically accelerates the corrosion of beryllium. This corrosion can be further accelerated (galvanic corrosion) if beryllium is in contact with a less reactive metal.

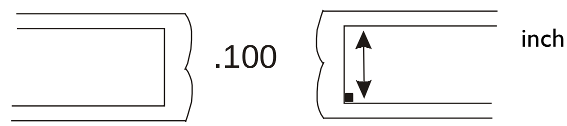
Beryllium can be protected from corrosion by contact with a more reactive metal (anodic protection). Very few common metals are more anodic than beryllium.

The galvanic corrosion potential is a measure of how dissimilar metals will corrode when placed against each other in an assembly. Metals close to one another on the chart generally do not have a strong effect on one another, but the farther apart any two metals are separated, the stronger the corroding effect on the one higher in the list. This list represents the potential available to promote a corrosive reaction; however, the actual corrosion in each application is difficult to predict. Typically, the presence of an electrolyte (e.g. Water) is necessary to promote galvanic corrosion.

Material	Remarks
Magnesium	Least Noble (+), Anodic
Zinc	
Beryllium	
Aluminum	
Cadmium	
Steel or Iron	
Stainless Steel, Series 300 (active)	
Nickel (active)	
Brasses, Bronzes	
Nickel (passive)	
Stainless Steel, Series 300 (passive)	
Titanium	
Silver	
Gold	
Platinum	Most Noble (-), Cathodic

Generally, some corrosion protection should be applied to beryllium. Salts from handling beryllium without gloves along with humidity in the air are sufficient to cause “finger print” corrosion on a bare beryllium part. A chromate conversion coating is an effective protection for non-severe service. For severe service, or for service where beryllium is exposed to salt spray or mist, an integral coating is needed to prevent corrosion. The conversion coating alone will not protect beryllium in salt spray applications. Conversion coating in combination with anodic protection with manganese or magnesium has been effective in protecting beryllium brake components on aircraft carrier based planes. Electroless nickel, epoxy paint and other integral coatings are effective corrosion barriers in salt spray applications. Electroplating has irregular plating distribution so allowances for edge and corner buildup must be made.





Electroplating will not plate all the way into blind holes, and will not cover uniformly through or threaded through holes in excess of ½ inch depth and .100 diameter as illustrated. As hole becomes larger, coverage will increase.

When painting is necessary, some military specifications on flight programs require as much as .003” (0.008 cm) thickness or primer and paint, which does not include build up on edges.

Design to the most important finish requirement first, and then work down the list in priority sequence.

- Corrosion Resistance
- Surface Hardness
- Ductility
- Solder ability
- Conductivity
- Lubricity
- Esthetics of Product
- Plating and Painting Tolerances
- Base material best for application
- Operating and Temperature environment

Always keep communication lines open between machining, fabricating, electroplating and painting vendors. This will save unlimited amounts of time and money, which, in turn, produces a more timely and superior product.

Plating. Materion has contracted with several plating vendors to provide services with typical one week turnaround. These limitations are basic:

Surfaces to be plated must be wetted by all solutions and rinses in the plating sequence

One must be able to make electrical contact without resulting defects

The amount of metal deposited on a given portion of a surface will be proportional to the current that flows to that surface portion.

On the other hand, it is necessary to be aware of the great influence that part configuration can have on the cost of plating and on the quality of the finished product.

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Coating Like aluminum, AlBeMet® materials form a protective oxide film on freshly machined surfaces, except the film on AlBeMet® is much more tenacious. For this reason, immediate coating after machining or grinding parts is critical. Coating the AlBeMet® surface resists corrosion and also provides a continuous bonding surface. Precleaning and proper coating applications are critical for the primer (usually a Phenolic-based epoxy compound) that is subsequently cured at 120˚C (250˚F).

AlBeMet® materials can be coated with typical aluminum protective coatings from Chemfilm (Alodine) to Cadmium over Nickel, depending on service environment. This would further decrease the weight of the system by another 30% over the absolute density difference in the materials. Current applications have passed 500µ salt fog test using methods including anodizing (Class I Type 1), electroless nickel plating and cadmium plating over nickel.

Once coating stabilizes the machined surfaces, coated parts may be stored for months, if necessary. After storage, a simple alcohol wipe removes any dust or fingerprints prior to further assembly operations. A quality fabricator can therefore furnish the product in a condition that the assembler/customer does not have to interface with the AlBeMet® materials in his subsequent assembly or mounting operations.

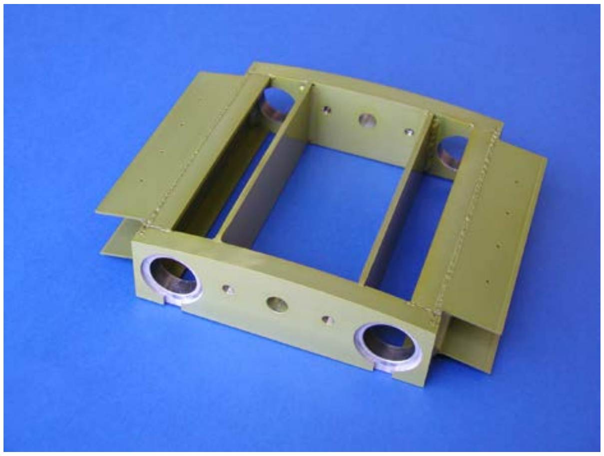
The finishes listed are procured on a daily basis and have been applied and successfully tested in a Salt Fog Chamber with a 5% solution at 95˚F (35˚C) for 500 hours. Note: Several patented hard coatings (wear resistance) have been successfully tried in Formula One racing (Poeton-UK and TMT-US).

Joining

The AlBeMet® materials can be joined by both electron beam welding and dip brazing methods. Brazing is chosen because of consistency and quality of joints. Expert fabricators of AlBeMet® materials have developed proprietary programs involving higher temperatures and longer times than those used for aluminum to obtain high-quality brazed joints. Design of joints for these metal matrix composites is quite different from those used for aluminum. Aluminum usually fails in a ductile manner, so bending occurs before failure, which usually occurs in the joint.

With AlBeMet® materials, the metal is stiffer so the joint is designed so the parent metal breaks before the joint fails.

In this fail-safe design, the joints are not the weak member in the design and will therefore take the stress build-up without failing. AlBeMet® material can be joined utilizing many of the same joining technologies for aluminum. The material can be vacuum and dip brazed, electron beam welded, TIG welded and there is currently work being done on laser welding technologies.



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MILITARY COATING NAME FOR ALBEMET®	SPECIFICATION
CHEMICAL FILMS	**MIL-C-5541E**
Conversion Coat – Materials qualified produce coatings that range in color from clear to iridescent yellow or brown. Inspection difficulties may arise with clear coatings because visual inspection does not reveal the presence of a coating.	*Class 1A* - For maximum protection against corrosion, for surfaces to be painted or left unpainted. Class 1A chemical conversion coatings are intended to provide corrosion prevention when left unpainted and to improve adhesion of paint finish systems to aluminum and aluminum metal matrix composites. May be used for all surface treatments of tanks, tubings, and component structures where interior paint finishes are not required. Repair of mechanically damaged areas of anodic coatings conforming to MIL-A-8625 will provide effective means of reestablishing corrosion resistance but will not restore abrasion resistance of the anodic coating. *Class 3* - Class 3 chemical coatings are intended as a corrosion preventive film for electrical and electronic applications where low resistance contacts are required.
CHROMIC (SULFURIC ACID) ANODIZE	**MIL-A-8625F**
Corrosion resistance requirements: salt spray requirement is 336 hours, 5% solution per method 811.1 of FED-STD-151 or ASTM B117 (surface inclined approximately 6 degrees from the vertical). The specimen panels or finished products shall show no more than a total of 15 isolated spots or pits, non larger than 1/32 inch in diameter, in a total of 150 sq. in. of test area grouped from 5 or more test pieces; or no more than 5 isolated spots or pits in a total of 30 sq. in. from one or more test pieces.	*Type 1A 0.00002" – 0.0003"*- Conventional chromic acid bath. Shall not be applied to aluminum metal matrix composites with over 5.0% copper, 7.0% silicon, or total alloying constituents over 7.5% (Note: metal matrix composites with higher than 8.0% silicon content may be anodized subject to approval of acquiring activity if supplier shows coatings equivalent to that on lower silicon contents.) *Type 1B 0.00002" – 0.0003"* - Low voltage chromic acid anodizing (20V). Use Type 1B for 7000 series metal matrix composites. Heat treatable metal matrix composites, which are to receive Type I coatings, should be tempered (as T_4 or T_6).
Minimum weight Type I coatings after sealing: *Class 1 – 200 milligrams/sq. ft.* Minimum weight Type I coatings after sealing: *Class 2 – 500 milligrams/sq. ft.*	*Class 1 Non-dyed* (natural, including dichromate sealing). *Class 2 Dyed*. Specify color on contract.
TEFLON IMPREGNATED ANODIZE W/DUPLEXED SEAL	**MIL-A-63576 A TYPE I**
TEFLON IMPREGNATED ANODIZE	**MIL-A-63576A TYPE III**
EPOXY PAINT	**BR127**
SULFAMATE NICKEL	**MIL-P-27418 (USAF)**
Soft gray ductile nickel plate. Additives may be used to harden.	*.000001 0-.200+* Electroforms, molds, electronic leads for ductility. Flexible circuits, soldering, brazing, PC boards, diffusion barrier in between gold over copper.

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MILITARY COATING NAME FOR ALBEMET®	SPECIFICATION
ELECTROLESS NICKEL	**MIL-C-26074E, CLASS 4 GRADE A**
Similar to stainless steel in color. Plates uniformly in recesses and cavities (does not build up on edges). Corrosion resistance is good for coatings over .001" thickness. Electroless nickel is used extensively in salvage of mis-machined parts. Also, for inside dimensions and irregular shapes (where assembly tolerances need uniformity provided by "electroless" process). (Unless otherwise specified*.)	*The minimum thickness of the nickel coating shall be 0.0003 inch (grade B0 for copper, nickel, and cobalt-based titanium and beryllium metal matrix composites.
Precoating and post coating procedures: *Class I below RC40. Bake at 375˚F ± 25˚F at user's option.* *Class I above RC40. Bake 375˚F ± 25˚F for 3 hours. Shot peen steel parts designed for unlimited life under dynamic loads prior to plating.*	*Class I* As plated, no subsequent heat treatment. A bake for hydrogen embrittlement relief is not considered a heat treatment.
Class 2 below RC40. Shot-peened parts designed for unlimited life prior to plating. *Class 2 above RC40.* Shot peened parts designed for unlimited life prior to plating. Post plating back 3 hours minimum 350˚F. Coating needs minimum hardness of 850 knoop (100 gm load).	*Class 2* Heat-treated to obtain required hardness. May be used on all metals not affected by heating to 500˚F and above.
Class 3 – Post bake 1-1/2 hours at 375˚F ± 25˚F.	*Class 3* Aluminum metal matrix composites non-heat-treatable, and beryllium metal matrix composites processed to improve adhesion of the nickel deposit.
Class 4 - Post bake heat treatable metal matrix composites 1-1/2 hours at 240˚F-260˚F.	*Class 4* Aluminum alloy, heat treatable, processed to improve adhesion of the nickel deposit. *Grade A - .001; Grade B - .0005" min.; Grade C - .0015" min.*

Handling aluminum-beryllium in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Safety Data Sheet (SDS) before working with this material. For additional information on safe handling practices or technical data on beryllium, please contact Materion Beryllium & Composites' Product Steward at 216-383-4040.

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