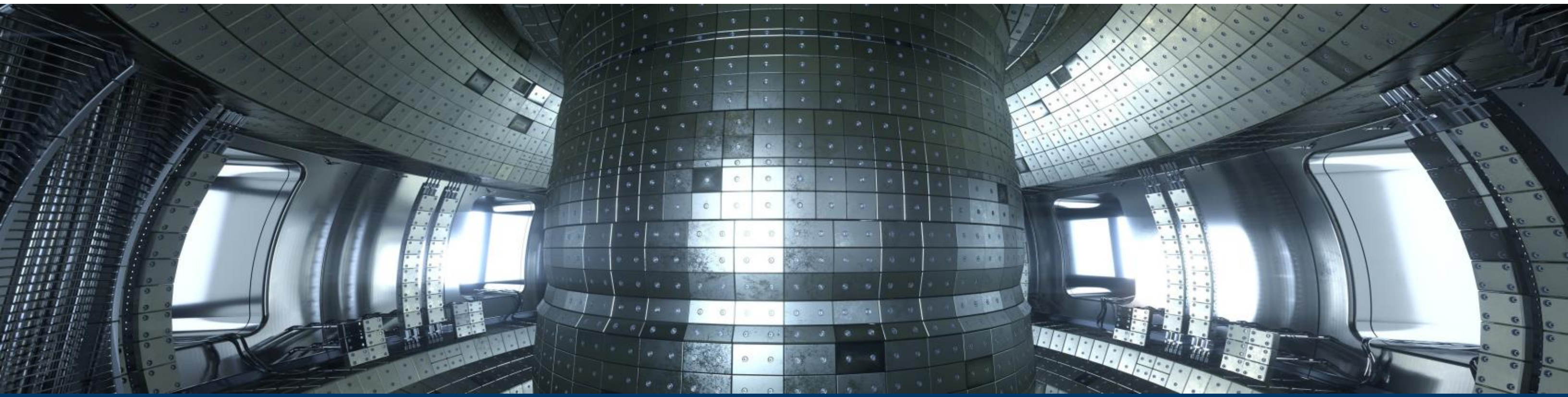
MATERION

DESIGN GUIDE

A GUIDE TO DESIGNING AND FABRICATING WITH BERYLLIUM



An introductory guide to the physical and mechanical properties, material selection and fabricating methods for beryllium.

What design challenges are you facing today?

INTRODUCTION

Beryllium is one of the lightest metals on earth with a unique combination of properties not found in any other material. Its high stiffness, high strength, low density, heat resistance, and reflectivity make it an exceptional material for demanding applications across a wide variety of industries – including aerospace, medical, space and defense.

The strength-to-weight and stiffness-to-weight ratios of beryllium are outstanding. It offers high specific heat and excellent thermal conductivity that allows the material to sustain crucial properties at both elevated and cryogenic temperatures.

Materion Corporation pioneered the development of beryllium and its derivative materials dating back to the 1920s. To this day, we mine our own ore (bertrandite) and process it at our mill in Delta, Utah. These reserves assure a reliable source of beryllium beyond the 21st century. The ore is then converted through a lengthy process into beryllium.

There are various grades of beryllium (i.e., material specifications) created from different methods of consolidation. Physical and mechanical properties are dependent on the grade and consolidation method of choice. Beryllium can be machined into shapes specified by our customers. We also produce beryllium plate, sheet, foil and deep-drawn blanks in-house.

BERYLLIUM: BY THE NUMBERS

Characteristic	Characteristic Measurement	Beryllium Facts
Atomic Number	4	Reflectivity: Optical reflectivity 50%, ultraviolet reflectivity 55%, infrared (10.6 μm) reflectivity 98%.
Atomic Weight	9.01	
Latent Heat of Fusion	582 Btu/lb. (1354 kJ/kg)	
Density	0.067 lb./in^3 (1.85 g/cm^3)	Sonic velocity: Velocity of sound in beryllium is 41,300 ft/second (12,588 m/sec), 2.5 times that of steel.
Melting Point	2345°F (1285°C)	
Electrical Conductivity	40.7% of IACS	X-ray transparency: Due to its low atomic number, beryllium transmits x-rays 17 times better than an equiva- lent thickness of aluminum. Beryllium x-ray windows allow the most efficient use of generation radiation in medical and analytical applications
Magnetic Characteristics	Beryllium is diamagnetic, -1.0 x 10-6 cgs units	

	SPECIFIC HEAT		MELTING POINT		THERMAL CONDUCTIVITY		COEFFICIENT OF THERMAL EXPANSION	
Metal	Btu/lb.·°F	J/kg·K	°F	°C	BTU/h·ft·°F	W/m·K	ppm/°F	ppm/K
Beryllium	0.46	1886	2345	1285	121	210	6.3	11.4
Aluminum	0.22	900	1220	660	143	247	12.7	22.8
Steel	0.12	502	2800	1538	30	52	6.7	12.0
Copper	0.09	385	1983	1084	230	398	9.2	16.5
2124 T6-30% v/o SiC	0.21	882	1180	638	88	152	11.7	21.1
2024 T6-25% v/o F-9	0.21	882	1180	638	88	152	11.7	21.1

PHYSICAL PROPERTIES

LOW DENSITY

Beryllium is one of the lightest structural metals known. Its density of 0.067 lbs./in^3 (1.85 g/cm^3) is two-thirds that of aluminum. Beryllium's light weight, coupled with its high stiffness and strength, make it ideal for applications requiring a favorable weight-to-stiffness ratio.

THERMAL PROPERTIES

Beryllium has a specific heat at room temperature of 0.46 Btu/lb.·°F (1886 J/kg·K), the highest heat capacity of all metals. This means for any given weight and temperature change, beryllium has the ability to absorb more heat than any other metal. This superiority is maintained up to its melting point of 2345°F (1285°C).

Beryllium also has the best heat dissipation characteristics among metals on an equal basis, with a thermal conductivity of 121 Btu/h·ft·°F (210 W/m·K) at room temperature. The material's coefficient of thermal expansion is 6.3 ppm/°F (11.4 ppm/K). These values are comparable to those for stainless steel, nickel alloys and cobalt alloys.

The thermal diffusivity of beryllium, 2.28 ft^2/h (0.21 m^2/h), assures rapid temperature equalization that tends to eliminate or greatly reduce distortion that might otherwise occur as a result of thermal gradients.

NUCLEAR PROPERTIES

The nuclear properties of beryllium, combined with its low density, are attractive characteristics for neutron reflectors and moderators in the design of reactors. Beryllium's high scattering cross-section makes it effective in slowing neutron speed to a level required for efficient reactor operations. This ability classifies beryllium as one of the few good solid moderators available.

Its major application, however, is as a reflector. In this capacity, beryllium acts to scatter leaked neutrons back into the reactor core. Neutrons are conserved because of beryllium's low thermal neutron capture cross-section. However, beryllium can be used to increase neutron flux density through the reaction, initiated with a fast neutron $Be^9 + n_f \longrightarrow 2\, n_0^1 + 2He$ for medical applications (n_f is denoted as a "fast neutron").

MECHANICAL PROPERTIES

The mechanical properties of beryllium vary with the production method used, such as vacuum hot pressing (VHP), hot isostatic pressing (HIP), cold isostatic pressing (CIP)/sintering or extrusion.

SHEAR STRENGTH

Shear strength represents how difficult it is to cut a material. The shear strength characteristics of beryllium in both hot-pressed and sheet form are unusual. The relationship between shear strength and tensile strength is greater than most materials at low temperatures, but at temperatures greater than 900°F (482°C), the ratio is lower than expected. These tests are conducted using tear-type specimens. The shear modulus for beryllium is typically 19 msi (131 GPa) for both the longitudinal and transverse directions. The average shear rupture modulus for S-200F is 44.8 ksi (309 MPa).

TENSILE STRENGTH

Tensile strength is a measurement of the force required to pull a material to the point at which it breaks. Ultimate tensile strengths of processed beryllium range from 50 ksi (345 MPa) for VHP block to 75 ksi (517 MPa) for HIP block. At elevated temperatures up to 1500°F (816°C), beryllium retains its strength, whereas other structural metals such as aluminum and magnesium would have already exceeded their melting point.

COMPRESSIVE YIELD STRENGTH

Compressive yield strength is a measurement of the force required to compress a material to the plastic deformation. The compressive yield strength (0.2% offset) at room temperature of beryllium is typically 10% higher than the tensile yield strength. At 400°F (204°C), the compressive yield strength remains about equal to the tensile yield strength. This is a unique property of beryllium and is demonstrated by S-200-F, where the room temperature tensile yield strength and compressive yield strength are about 37 ksi (255 MPa).

NOTCHED STRENGTH

Notch strengthening occurs in beryllium at temperatures around 400°F (204°C) over a wide range of stress concentration factors. In fact, S-200-F, with a notched ratio of 1.21 at 400°F (204°C), S-200-F has a notched tensile strength that is greater than the un-notched strength. At room temperature, the notched strength ratio of S-200-F is approximately one (1.0).

FRACTURE TOUGHNESS

A growing interest in beryllium as a structural material has been accompanied by an increasing interest in the toughness of this material. When the more common vacuum hot-pressed structural grades of beryllium, S-65 and S-200-F, are tested, a KIC value of 9-10 Ksi·√in (10 – 11 MPa·√m) at room temperature can be expected.

CREEP

Creep is the tendency of a material to slowly deform under the influence of mechanical stresses. It is more severe in materials that are subjected to heat for long periods, and it generally increases as they near their melting point.

Through the use of the Larson-Miller parameter, which is a means of predicting the lifetime of material vs. time and temperature it is subjected to, the time and temperature to produce 0.1%, 0.5% and 1.0% plastic creep at any given stress can be obtained. Creep properties should be given serious consideration if high operational stresses are to be maintained at temperatures above 1000°F (538°C).

MODULUS OF ELASTICITY

One of beryllium's most outstanding features is its modulus and resulting stiffness-to-density ratio. When compared to other metals, the specific modulus of beryllium is superior by a factor of seven from room temperature to 1200°F (649°C). Beryllium has a modulus of elasticity of 44.0 msi (303 GPa), four times that of aluminum, two and a half times that of titanium and twice that of 40% SiC reinforced aluminum and various grades of graphite epoxy. For lightweight applications requiring a high specific value of elasticity, beryllium is unsurpassed.

MATERIAL SELECTION GUIDE

BERYLLIUM POWDER

The production of beryllium powder begins with the extraction of the metal from the ore through a series of crushing, grinding, and chemical flotation operations. Primary beryllium is produced as "pebble" by the magnesium reduction of anhydrous beryllium fluoride. The pebbles are vacuum-melted to remove high upper pressure elements and then cast into ingots.

In the cast form, the metal is very difficult to machine, and mechanical properties are poor. For these reasons, virtually all beryllium enters service as a powder metallurgy-derived product. Powder is prepared by chipping the ingots and mechanically grinding the chips to the appropriate particle size distribution for consolidation into essentially full-density billets by powder metallurgy techniques.

Historically, mechanical grinding systems used to manufacture beryllium powder have been shown to affect the characteristics of the fully dense body prepared with the powder. This is most notable in the level of minimum tensile elongation that can be generated in any direction at room temperature. This is true because of the anisotropy of the basic beryllium crystal with room temperature slip capability limited to a single direction coupled with basal plane cleavage as a major fracture mode. Historical grinding procedures for beryllium resulted in a powder with a high fraction of particles, with a flat plate configuration that oriented the powder's basal plane during handling and consolidation operations.

Impact grinding is a procedure for grinding chips to powder involving the impact of a beryllium chip propelled by a high-pressure gas against a beryllium target. The consolidated beryllium manufactured from this type of powder may exhibit, among other characteristics, high elongation so that a minimum of more than 1% at room temperature may be guaranteed.

VACUUM HOT PRESSED BLOCK

One of the most common forms of consolidated beryllium is vacuum hot-pressed block. The hot-pressing operation, consisting of the application of heat and pressure to beryllium powder contained in a suitable die, results in a uniform, fully dense, fine-grained beryllium that has been thoroughly out-gassed by the use of vacuum during the operation.

Through control of chemical composition, particle size distribution, and temperature, it is possible to produce beryllium grades with differing characteristics for many divergent applications.

STRUCTURAL GRADES

The specification numbers that identify the structural grades of beryllium vacuum hot-pressed block are S-65 and S-200-F.

S-65 is a premium material that is guaranteed to exhibit a minimum of 3 percent tensile elongation at room temperature. This strain capacity is obtained through the use of impact grinding during powder manufacture and was used in the window frames, umbilical doors and navigational base of the space shuttles. S-65 grade is the reference grade of beryllium for the International Thermonuclear Experimental Reactor (ITER), a fusion energy program, because it has superior chemical properties and is resistant to cracking under high heat flux thermal cycling.

S-65 is lower in oxide content than other grades at 0.9% maximum. While it has a higher guaranteed minimum room tensile elongation in the vacuum hot pressed form, it is lower in strength than our standard purity structural grade, S-200-F.

Grade S-200-F is most frequently used for parts machined from vacuum hot-pressed block. Typical data for this material is given in accompanying charts. S-200-F is a versatile material, and it has become a successful entity in a wide variety of applications – such as inertial guidance systems, missile interstages, optical substrates, spacecraft structures and small rocket nozzles.

INSTRUMENT GRADES

I-220-H is instrument grade beryllium. It is hot isostatically pressed beryllium that has been developed for applications where high micro-yield strength, i.e. the stress required to produce the first micro-inch of permanent strain (also known as the micro-yield strength or MYS), is required.

I-220-H is manufactured using impact ground powder consolidated by an isostatic process (hot isostatic pressing, or HIP).

	S-65	S-200-F
CHEMICAL COMPOSITION		
Be, min%	99.2	98.5
BeO, max%	0.9	1.5
Al, max ppm	500	1000
C, max ppm	900	1500
Fe, max ppm	800	1300
Mg, max ppm	100	800
Si, max ppm	450	600
Other, each max ppm	400	400
	BeO specified is minimum in this instance	
MINIMUM TENSILE PROPERTIES		
Ultimate Tensile, ksi (MPa)	42 (290)	47 (324)
Yield Strength (0.2% offset), ksi (MPa)	30 (207)	35 (241)
Elongation, %	3%	2%
Microyield, ksi (MPa)	—	3 (27)
STANDARD SIZES*		
Inches (cm)	32 dia x 30 lg (81 x 76)	32 dia x 45 lg (81 x1 14)

*Pressing (billet) sizes can range from 7" (18 cm) and 6" (15 cm) to 66" (168 cm) in length, depending upon grade and chemistry.

OPTICAL GRADES

The specification numbers that identify optical grades of beryllium are I-70-H, I-220-H, O-30-H and S-200-F. A hot isostatically pressed atomized beryllium powder optical grade O-30-H was developed to provide an improvement over the standard grade for bare polished beryllium optics. At 0.5 wt% maximum BeO, it is the lowest oxide powder derived beryllium that has ever been marketed.

I-70-H sintered maximum of 0.7 wt% BeO and is manufactured by controlling impact ground powder. Both I-70-H and O-30-H are manufactured by hot isostatic pressing (HIP), yielding a more isotropic material than any previously available optical grade of beryllium.

I-220-H beryllium is made with guaranteed minimum micro-yield strength and is used where the optical surface is a hard polished electroless nickel. Mirrors of this type are used in the visible and infrared wavelengths of light or any system that may require high resistance to plastic deformation due to severe G-loads or other working stresses.

Grades S-200-F and S-200-FH have been used successfully as an optical substrate and support bench in many astronomical telescopes, in fire control and FLIR systems, and in earth resources and weather satellites. In most applications, the optical surface of S-200-F is a hard-polished coating of electroless nickel - 24 micrometers to 150 micrometers thick. Electroless nickel is harder than bare beryllium and more easily polished to a fine surface finish.

WROUGHT FORMS OF BERYLLIUM

Wrought forms of beryllium are usually produced from vacuum hot-pressed blocks by conventional working techniques carried out either in warm or hot working temperature ranges. Wrought products exhibit improved strength and tensile elongation relative to the hot-pressed block in the direction of metalworking. This is due to the crystallographic orientation resulting from the working operations. Multi-directional working schedules are frequently used to alleviate this effect.

ROLLED BERYLLIUM SHEET AND FOIL

Beryllium sheet and foil is flat stock with a thickness of 0.250" (6.350 mm) or less. The foil is manufactured by rolling the material at elevated temperatures. Beryllium cannot be rolled at room temperature or cooler.

Because of its low absorption of radiation, beryllium foil is used in windows that transmit different wavelengths of radiation, both in detector and source applications. It is used specifically in X-ray transparent applications such as analytical spectrometers and mammography equipment. Due to the nature of these applications, it is typically available in high-purity grades.

IF-1 is the highest purity foil (99.8% Be) and is available as standard products in thicknesses between 0.0003" (7.6 µm) and 0.020" (500 µm). PF-60, which is 99% pure Be, is available at gauges starting at 0.001" (25.4 µm) and up to 0.125" (3200 µm). IS-50M (99% Be) is designed specifically for mammography applications that require material that is radiographically artifact free, available in gauges from 0.020" (0.51 mm) up to 0.125" (3.18 mm)

ROLLED BERYLLIUM PLATE AND SHEET

By convention, beryllium rolled stock with a gauge between 0.020" (0.51 mm) and 0.250" (6.35 mm) is known as sheet, while thicker gauge material is referred to as a plate. The specifications are SR-200 for sheet between 0.020" (0.51 mm) and 0.220" (5.56 mm) and PS-200 for sheet between 0.005" (0.13 mm) and 0.250" (6.35 mm) inclusive. The difference between the grades is that SR-200 is hot-rolled and has minimum mechanical properties. In plane tensile minimum, tensile properties are 70 ksi (483 MPa) ultimate tensile strength, 50 ksi (345 MPa), 0.2% yield strength and 10.0% elongation.

The chemical composition of both of these products conforms to that previously listed for S-200-F vacuum hot-pressed block. These rolled products are manufactured by hot rolling billets of vacuum hot-pressed block. The properties of SR-200 sheet are balanced by cross rolling (i.e. rotation of the rolling direction 90°) during the reduction schedule.

I-220-H is manufactured using impact ground powder consolidated by an isostatic process (hot isostatic pressing, or HIP).

NEAR NET SHAPES

Despite a combination of physical, mechanical, and thermal properties that is unequalled by any other material, beryllium's uses recently expanded by its availability in hot isostatically pressed forms. This form reduces total manufacturing by reducing the required amount of powder and reduced machining time, controlling overall net cost.

Near net shapes can be produced to avoid the high part cost associated with the installation and development of production facilities.

The use of hot isostatic pressing (HIP) and cold isostatic pressing (CIP), along with the conventional cold pressing technology, allows beryllium to be used in a wider range of applications.

HOT ISOSTATIC PRESSED GRADES

The specification numbers that identify the grades that are available by HIP are S-200-FH, S-65-H, I-70-H, I-220-H and O-30-H.

The S-200-FH grade utilizes impact ground powder that is consolidated in a sheet metal can be formed into the shape of the final part. In production, the can is degassed, sealed and HIP'ed—typically at 850°C to 1000°C or 1560°F to 1830°F and 15 ksi (103 MPa).

The S-200-FH material is isotropic and has higher density (99.8% minimum of theoretical) and more desirable mechanical properties than the traditional vacuum hot-pressed material. It is useful for structural applications or those requiring low weight, high mechanical strength, and a high fatigue endurance limit.

Grade I-220-H is a high-strength, moderate ductility material useful for structural, instrument, and optical applications as well as those requiring high resistance to plastic deformation at low stress levels. It offers the best combination of high tensile strength, ductility, and MYS of any grade of beryllium. Its MYS (amount of stress required to produce one micro inch of permanent strain) is either 6 ksi (41 MPa) or 8 ksi (55 MPa), depending upon subgrade.

S-65-H has a lower impurity content that is more compatible with nuclear energy applications. It is recommended for applications that need high ductility at elevated temperatures.

CIP and sinter grades' specification number S-200-FC identifies the only grade currently available by CIP. This grade utilizes impact ground powder that is compacted in a flexible rubber bag which approximates the final shape of the part. The powder is loaded into the bag and is degassed, sealed and CIP'ed typically 40 ksi (276 MPa) at room temperature. The part is then sintered to final density, 99+%, and—if required—may be hot formed to final shape. Minimum properties of S-200-FC beryllium are 38 ksi (262 MPa) UTS, 25 ksi (172 MPa), yield strength and 2% elongation.

This process is useful for applications requiring high modulus but less strength and density than those obtained by HIP. The tooling is reusable, making it economically advantageous for parts required in the hundreds. Typical applications of these grades are optics for fire control systems in tanks and aircraft, as well as instrument applications such as inertial measurement units.

Seamless Iterative Process involves using net shaping technology and mold design iterations to minimize machining set-up time and tooling by making rough blanks and finishing to the designer's print. Successive iterations improve and reduce material cost by performing needed mold changes without compromising quality or schedules in the supply chain.

EXTRUSIONS

Extrusion is a conventional approach to the creation of rod, thick-walled beryllium tubes, or shapes. For specific applications, extrusion provides consistent mechanical properties, dimensions, and tolerances. Sections are made to dimensions that are well within commercial tolerances and mechanical properties that are superior to those of hot-pressed block in the direction of metal flow. Directional properties are produced in varying degrees as a function of crystallographic orientation.

The input billets for extrusions are usually machined from consolidated hot-pressed block. The billets are jacketed in cans with shaped nose plugs and are extruded through a die in temperature ranges between 1650°F (899°C) and 1950°F (1066°C). The jackets are later removed by chemical means.

Rod, tubing, and structural sections are the most common extruded shapes. Rod is available in sizes from 0.375" to (9.53 mm) to 5.75" (146 mm) diameter, tubing from 0.25" (6.35 mm) to 0.020" (0.51 mm) wall thickness.

Some current examples of extruded shapes include boom arms for solar array panels, satellite truss supports, draw stock for wire, fuel element cladding, and input for co-extrusions with dissimilar metals. Mechanical properties and chemistry are tailored to the specific application. Beryllium extrusions have typically been made from the standard structural grade, S-200-F.

ELECTRONIC GRADES

Cross-rolled SR-200 beryllium sheet is utilized as a combination heat sink and structural support in military electronic and avionic systems.

Constraining cores made from this material are attached to surface-mounted (SMT), printed circuit boards to alleviate the mechanical stress on the solder joints of leadless and leaded ceramic chip carriers (LCCCs). The high thermal conductivity of beryllium is needed to dissipate the heat generated by the combination of large-scale integration and high switching speeds.

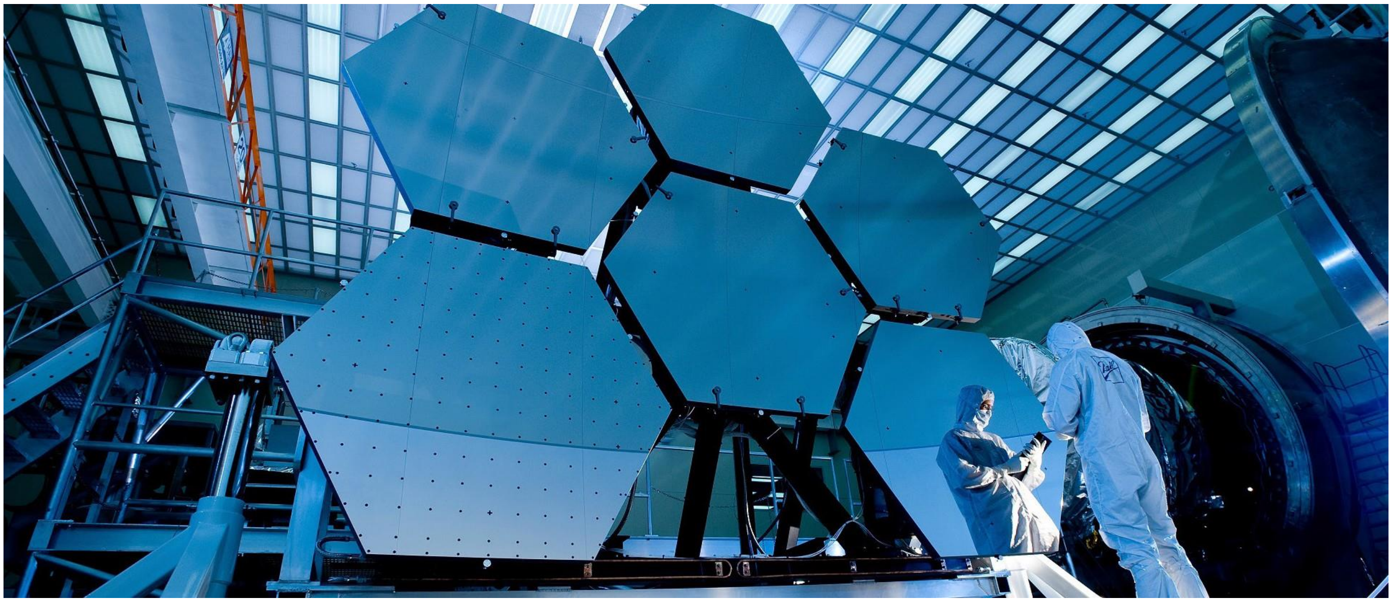
The applications also require a coefficient of thermal expansion (CTE) that is a good match to the alumina and polyimide glass substrates used in the system. Beryllium has a mean CTE of 6.3 ppm/°F (11.4 ppm/°C) at room temperature to 212°F (100°C).

The major appeal of beryllium, however, is its low density. Since about seven pounds of payload or fuel can be added for every pound saved in the electronics systems of space and airborne vehicles, this is a matter of prime importance. Compared to other core plate materials, beryllium weight is about one-fifth as much as copper-clad molybdenum and one-fourth as much as copper-clad invar.

In addition to its light weight and desirable thermal properties, beryllium possesses high specific stiffness, high modulus of elasticity, and minimal interaction with magnetic fields.

Dimensional stability is an important attribute in constraining core plates, because any tendency of the material to vibrate, flex or bend would be used as traumatic to the printed circuit board (PCB) as expansion/contraction. In terms of specific modulus, beryllium far outperforms the other candidates.

Beryllium not only dissipates heat, but it also readily absorbs heat when necessary. The specific heat of beryllium is four times that of Cu Invar/Cu and six times that of Cu/Mo/Cu.



FABRICATION PROCESSES

MACHINING BERYLLIUM

Generally, beryllium can be machined to intricate forms, maintaining excellent surface finishes and close tolerances with proper machining practices. Machining practices for beryllium parallel those of cast iron. Generally, tool design for cast iron will be applicable. Beryllium has a machinability factor of 55% using AISI 1113 steel as 100%. It is a comparatively soft, low-carbon material (Rb 80-90) but abrasive, producing a discontinuous chip. Generally, Grade 2 general purpose carbide for cast iron and non-ferrous metals is selected as the cutting tool material. Selective specific grades in the class, such as Valentine VC-2 or equivalent, will give excellent results.

Care should be taken to secure clean, uncontaminated beryllium chips when removing substantial quantities of metal for economic reasons because of the high value of such clean chips. Contamination of chips results in the necessity of expensive reclamation procedures before such metal can be reintroduced into the manufacturing stream. Beryllium should not be machined until it is certain that the required limits on airborne beryllium will be observed. More information on this subject appears in the final Health and Safety section and important guidelines for safe handling procedures are included in the Safety Data Sheet (SDS).

Beryllium is quite susceptible to surface damage as a result of machining operations. This damage may be seen by careful sectioning of machined material and observing the microstructure of the disturbed surface layers, twins, and even cracking in severe cases. The damaged layer may be of varying depth and dependent upon the severity of machining operation, condition of tooling cutting edges, etc. Generally, with good practice, it does not exceed 0.002" (50 µm) in depth, but it may reach 0.008"-0.010" (203-254 µm) in severe cases. The result of such damage, if not removed, is a dramatic decrease in the ultimate tensile strength and elongation of the metal; yield strength might also be affected. Machine damage is controlled by adherence to accepted machining practice followed by etching to remove 0.004 in. (102 µm) per side or by heat treatments designed to anneal out the disturbed twinned grain structure. In summary, beryllium can be readily and successfully machined into intricate and very precise tolerance components using standard metal cutting and finishing techniques when using appropriate machining practices.

DRILLING OF WROUGHT PRODUCTS

The key to successful drilling of wrought products involves control of the feed rate and selection of drill points that minimize tool pressure. Improper control of any factor in this process can result in laminar breakout or delamination within the product. To prevent the occurrence of such a problem, the use of a drill with the ability to vary the speed and feed in order to maintain the cutting force within safe limits for both the drill and the beryllium is recommended. A straight two-fluted carbide or carbide-tipped drill is recommended and commercially available.

SHEET CUTTING

Straight cuts are made in-sheet by an abrasive sawing technique. This operation is performed wet using a resin-bonded, semi-friable aluminum oxide wheel rotating to give a surface speed of 7,000 to 9,000 rpm (35.6 to 45.7 meters per second). Using a wheel with an abrasive grain size of 80 grit and a relatively soft “L” bond grade is recommended.

CHEMICAL MILLING

Chemical milling techniques have been successfully used in the fabrication of parts made from beryllium block, sheet extrusion and forgings. Metal removal may be over the entire surface, or it may be restricted to selected areas by masking. The important steps in chemical milling operations are as follows: clean, mask, scribe, and strip mask before milling; milling and mask removal after milling. Material removal rates vary from 0.001" (25 µm) to 0.002" (51 µm) per minute, using a 2% HF/ 2% HNO_3 2% H_2SO_4 acidic mixture (with a balance of deionized water). Tolerances on the final part are very close to those of the original and can be held at +/-0.005" (+-127 µm) for material removal of approximately 0.100" (254 µm). Tolerances can be expected to vary in complex configurations with higher mill rate at external radii. Surface finishes are generally rougher after chemical milling and depend, to a great extent, on starting material surface quality.

ELECTROCHEMICAL MACHINING

Successful trepanning, contouring and drilling of complex beryllium parts have been carried out using electrochemical machining. This process is attractive because it produces a relatively small degree of surface damage.

ELECTRIC DISCHARGE MACHINE (EDM)

EDM is very effective on beryllium and is used to machine intricate and irregular forms at good production rates. Plunge EDM process is generally carried out using copper or graphite cathode tools, which enhance metal removal rates, and deionized water or dielectric oil that acts as a coolant.

This method is very practical for the machining of complex shapes of beryllium. Beryllium can also be cut successfully to precise tolerances by using a wire EDM machine. Deionized water is a good coolant and flush media. High strength brass, molybdenum or coated steel have been used as the wire electrode.

JOINING METHODS

ADHESIVE BONDING

Adhesive bonding is a very desirable way to join beryllium to itself and other metals. The method of joining permits the utilization of the desirable mechanical and physical properties of the metal while minimizing notch sensitivity.

Depending on the application of the part to be joined, specific adhesives from the low temperature to the high temperature range are available. Of all the steps involved in producing a good bonded joint, surface preparation is the most important by far.

Once the adherents have been acid-cleaned and neutralized, the adhesive is applied. The joint is then exposed to heat and pressure, characteristic for each specific adhesive, for about one hour. If, for any reason, the parts must be taken apart, the adhesive must be removed, and the procedure repeated with a clean surface.

BRAZING

Brazing is another means of joining beryllium to itself and other metals. Which technique to use depends on the specific application of the beryllium part. Typically, a silver base, zinc base or aluminum base alloy is used, providing the designer-varied strength and thermal capabilities. Brazing is considered the most reliable method of metallurgically joining beryllium.

ELECTRON BEAM WELDING

Electron beam welding is successfully carried out, particularly in instrumentation assemblies, where severe structural requirements are not present.

DIFFUSION BONDING

Diffusion bonding can be carried out with beryllium and has been used for assemblies.

FURNACE BRAZING

The technique of furnace brazing has been used successfully with beryllium using a silver braze alloy with 0.50% lithium content. This technique involves replacing the braze alloy between two halves of the assembly. The joint is then subjected to static loads at high temperatures. The brazing is done in a vacuum to prevent oxidation of the beryllium at the elevated temperature.

COATINGS

Beryllium, much like aluminum, develops an adherent and protective oxide coating in air. Due to this phenomenon, oxidation in dry air is minimal for short periods of time up to temperatures of about 1400°F (760°C).

However, in other environments, the protection may not be adequate, and care must be exercised to avoid corrosion. Beryllium that is clean and free of surface contamination has good corrosion resistance in low-temperature/low-humidity environments. However, beryllium is highly susceptible to localized pitting when in contact with the chlorine, fluorine or sulfate ions contained in ordinary water. Therefore, exposure to tap water should be kept at a minimum and always followed by a rinse with deionized water, followed by drying to insure against damage. Seawater is very corrosive to beryllium. The handling of beryllium parts with a finished surface should also be done with care. A fingerprint left on the surface will disrupt the effectiveness of the final etch or coatings. When corrosive conditions are anticipated, the use of a protective coating is advised.

An extensive amount of work was carried out to develop coatings and protective systems for beryllium operating in hostile environments. Coatings are also used to develop surfaces on beryllium that have characteristics other than that of beryllium itself. A few of these coatings are described below.

PASSIVATION

A beryllium surface exposed to chromate solutions will become passive and relatively stable. Adherence of strain gauges to such a surface or deposition and adherence of electroplated metal is extremely difficult. Berylcoat D is marketed by Materion as one treatment of this type that will aid in the prevention of "on the shelf" corrosion problems with the precise instrumentation. No measurable change in dimension or appearance results with the use of the treatment.

ANODIZING

Chromic black or "black" anodization of beryllium is employed extensively to provide corrosion protection to beryllium surfaces, to increase emissivity and to depress light reflectivity in optical systems. As deposited, the anodized coating is electrically conductive but becomes non-conductive after proper curing. Excellent resistance to salt spray and high-temperature oxidation has been reported for anodized beryllium. The surface finish of an anodized beryllium part is the same as that of the part prior to anodizing. In other words, it can be either highly reflective or matte in nature.

PLATING

A number of metals have been electroplated on beryllium. Electroless and electrolytic nickel plating have been used extensively with beryllium, especially in the optics field where the nickel plate is utilized in developing the optical figure and final polish of beryllium mirrors.

CHROMATE CONVERSION COATING

Enhanced resistance of salt spray and high temperature oxidation are provided to beryllium by chromate conversion coating developed for aluminum (e.g. Iridite® or Alodine). These coatings are formulated and applied following the instructions for use on aluminum.

STRENGTH OF ADHESIVE BONDED BERYLLIUM JOINTS

ADHESIVE SYSTEM	AVERAGE STRENGTH	TYPE/BOND
EA-9309-BR127 Primer	4700 psi (32.4 MPa)	Lap Shear
HT-424-BR127 Primer	2500 psi (17.2 MPa)	Lap Shear
FM-123-BR127 Primer	3500 psi (24.1 MPa)	Lap Shear
FM-123-BR127 Primer	55 lb./in (985 MPa)	Honeycomb Peel
EA-934-BR127 Primer	75 Shore D	Hardness
Epoxy Np. 206 – Grade A	3500 psi (24.1 MPa)	Lap Shear
BR127 Primer	K40 lb./in (716 kg/m)	90° Peel

STRENGTH OF BERYLLIUM JOINTS

ADHESIVE SYSTEM	AVERAGE SHEAR STRENGTH
Silver – Lithium (0.2%)	30.0 ksi (206.8 MPa)
Silver – Copper (28) 35.0 (241.3)	35.0 ksi (241.3 MPa)
Easy – F10 (50 Ag, 15.5 Cu, 16.5 Zn, 18 Cd)	44.0 ksi (303.4 MPa)
Aluminum-Silicon (12%) 15.0 (103.4)	15.0 ksi (103.4 MPa)
Epoxy Np. 206 – Grade A	3.5 ksi (24.1 MPa)
BR127 Primer peel test	40 lb./in (716 kg/m)

HEALTH AND SAFETY

Processing beryllium-containing products poses a health risk if safe practices are not followed. Inhalation of airborne beryllium can cause serious lung diseases in some individuals. Occupational safety and health regulatory agencies worldwide have set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Safety Data Sheet (SDS) before working with this material. The SDS and additional important beryllium health and safety information and guidance can be found at berylliumsafety.com, berylliumsafety.eu and Materion.com. For questions on safe practices for beryllium-containing products, contact the Materion Product Stewardship Group at +1.800.862.4118 or contact us by email at Materion-PS@Materion.com.

AVAILABILITY

Beryllium's unique blend of engineering properties—stiffness, high strength, low density, heat resistance and reflectivity—has opened the doors to countless new applications in recent years. If your design requirements fit any of these parameters, investigate the possibility of using beryllium or one of its related materials. The Sales and Engineering staff at Materion Performance Alloys and Composites will be glad to help.

To talk with an engineer about a specific application, call Materion today at +1 800-375-4205.

BERYLLIUM PRODUCTS	PRODUCTION PROCESS	AVAILABLE FORMS	MATERIAL SPECIFICATIONS
STANDARD MILL PRODUCTS	Vacuum Casting	Ingot, Lump & Chips	B26D
	Vacuum Hot Pressing & Machining	Block, Billet, Rod, Bar & Tube	S-200-F, S-65
	Rolling	Foil Discs & Rectangular Sheet & Plate	SR-200, PS-200, PF-60, IS-50M
	Hot Isostatic Pressing	Near Net Shapes	S-200-FH, I-220-H, S-65-H, I-70-H, O-30-H
NON-STANDARD MILL PRODUCTS	Hot Isostatic Pressing	Near Net Shapes	S-200-FH, O-30-H, S-65-H, I-70-H & I-220-H
	Cold Isostatic Pressing	Near Net Shapes	S-200-FC & S-65

MATERION

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