GUIDE TO LIGHTWEIGHT MATERIALS

MATERION

GUIDE TO
LIGHTWEIGHT MATERIALS

MATERIAL GUIDE

In this section you will find information about a variety of Materion products, including high-purity beryllium metals, metal matrix composites, alloys and even beryllium ceramics.

In addition to the products listed in this guide, unique solutions can be provided to meet specific performance requirements. Please contact one of our engineers for more information.

SupremEX® metal matrix composites (MMCs) are a family of materials based on high-strength aluminum alloys that are reinforced with nano-to-micron sized ceramic particles. The applications for SupremEX MMCs are varied and include mirrors, support structures, optical housings, electronic housings, waveguide structures, adapters and interface components.

AyontEX® alloys are a series of hypereutectic aluminum-silicon alloys containing micron-sized silicon particles in an aluminum alloy matrix. This ultrafine reinforcement provides several key benefits: high specific stiffness and strength, reduced coefficient of thermal expansion (CTE), excellent fatigue performance, improved damping, low friction and outstanding wear resistance.

AlBeMet® and **AlBeCast®** composites are made up of 62% beryllium and 38% aluminum. They have a specific stiffness higher than other metals, alloys or composites other than pure beryllium. Some applications are found in the optics, satellite structures, avionics and semiconductor industries.

Beryllium metal has a high modulus and low density giving it the highest specific stiffness of any metal. Beryllium has high thermal conductivity and a high specific heat capacity. It is essentially transparent to X-rays and has unique nuclear properties. Uses include satellite structures as well as optical, nuclear, defense, medicine and acoustic applications.

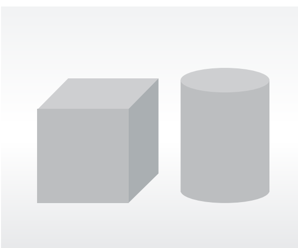
Beryllium oxide ceramic (BeO) has a thermal conductivity higher than most metals but is still an insulator like other ceramics. Materion's BeO and aluminum oxide (Al_2O_3) ceramic materials are ideal for addressing challenges in power electronics, semiconductor manufacturing and more.

MATERION

Product Forms

Materion's lightweight metals are available in a variety of product forms. The product forms available for each material are shown in the table. Descriptions of the forms have also been provided.

Block includes rod, bar, tube and shape products sawed and machined from consolidated billets. The maximum cross section varies based on the processing route.



Cast pieces of B-26-D are available in lump or larger pieces.

Cast shapes are available with AlBeCast® composites and are investment cast shapes with solid or hollow cross sections. Using these near-net shapes reduces part input weight and machining time, reducing cost.

Custom performance solutions can be made to specification from drawings supplied by the customer. Such products are fabricated from basic product forms by processes such as machining, forging, plating and welding. Allowable processes vary by product line.

Extrusions can be rod, bar, tube or shapes, depending on the material. These are available in AyontEX®, SupremEX® and AlBeMet® materials.

Foil is very thin beryllium metal between 0.025 mm (0.001 in.) and 3.18 mm (0.125 in.). Foil can be supplied in sheets with thicknesses as low as 0.20 mm (0.008 in.) and areas of 25 cm² (4 in²) or larger.

Forgings are supplied in forms ranging from simple geometric configurations to near net shapes according to user specifications.


SupremEX Forging

Near net shapes are materials consolidated in a geometry closer to the finish part shape to minimize raw material requirements and machining.

Plate is flat-rolled or forged product thicker than 4.8 mm (0.188 in) and over 30.48 cm (12 in) wide.

TABLE 1.1

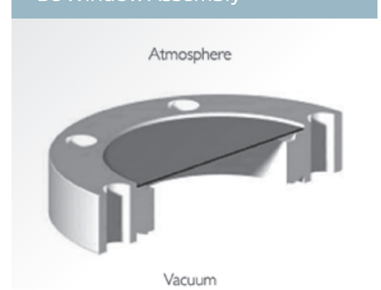
MATERION LIGHTWEIGHT MATERIALS — PRODUCT FORMS	BLOCK	CAST PIECES	CAST SHAPES	PERFORMANCE SOLUTIONS	EXTRUSIONS	FOIL	FORGINGS	NEAR NET SHAPES	PLATE	SHEET	X-RAY WINDOW ASSEMBLIES
SupremEX 215XK	X			X	X		X	X	X		
SupremEX 225XE	X			X	X		X	X	X		
SupremEX 225XF	X			X	X		X	X	X		
SupremEX 620XF	X			X	X		X	X	X	X	
SupremEX 640XA	X			X			X	X	X		
AyontEX 13	X			X				X	X		
AyontEX 17	X			X	X		X	X	X		
AyontEX 4632	X			X	X		X	X	X		
AlBeMet 162	X			X	X					X	
AlBeCast 910			X	X							
I-70H	X			X				X			
I-220H	X			X				X			
S-65	X			X							
S-65H	X			X				X			
B-26-D		X									
S-200F	X			X							
S-200FC				X				X			
S-200FH	X			X				X			
SR-200				X						X	
IF-5				X		X					X
PF-60				X		X					X
PS-200				X		X					X
Acoustic Foil				X		X					X
Ceramic	X			X				X			

Sheet is flat-rolled product 0.5 mm (0.020 in.) to 6.3 mm (0.249 in.) thick. The width and length vary with thickness and grade of material.

Windows are discs or rectangles of beryllium foil cut from foil stock.

X-Ray Window Assemblies include bonded window assemblies and catalog ConFlat UHV window assemblies.

Cutaway of Standard UHV Be Window Assembly



PHYSICAL PROPERTIES

Density is mass per unit volume, a measurement which sets these materials apart from Materion's other high-performance products.

Elastic modulus is the measurement of resistance to elastic deformation under stress and is sometimes called stiffness. Beryllium has a high modulus, approximately four times that of aluminum and six times that of magnesium.

Specific stiffness is the ratio of the elastic modulus to the density. A material with a high specific stiffness is ideal for reducing mass on structures, especially those to be launched into space.

Coefficient of thermal expansion indicates the extent to which a material expands with an increase in temperature. This value increases as temperature increases. All listed CTE data is given with respect to an initial temperature of 25°C. The low CTE of these materials allows them to be stable over a wide range of temperatures, making them well-suited for a variety of applications.

Thermal conductivity is a measurement of a material's ability to transfer or conduct heat. Materion's aluminum-based materials, beryllium metals and even beryllium oxide ceramic have high thermal conductivity.

Specific heat capacity quantifies heat per unit mass required to raise a material's temperature by one degree and is commonly given as kJ/kg·K.

Electrical conductivity is specified in % IACS (International Annealed Copper Standard). A material with 100% IACS conductivity has an electrical resistivity of 1.72 µΩ·cm (6.79 µΩ·in). The conductivity of a given material is expressed as a ratio of this theoretically maximum value.

Poisson's ratio is a measurement of material deformation in a direction perpendicular to that of the applied force. Beryllium in particular is known for its very low Poisson's ratio.

MATERIAL	DENSITY	ELASTIC MODULUS	SPECIFIC STIFFNESS	COEFFICIENT OF THERMAL EXPANSION[A]	THERMAL CONDUCTIVITY[B]	SPECIFIC HEAT CAPACITY[B]	POISSON'S RATIO
METRIC	g/cm^3	GPa	$GPa/g/cm^3$	ppm/°C	W/m·K	kJ/kg·K	
U.S. IMPERIAL	lb/in^3	10^6 psi	$lb/in^3/10^6$ psi	ppm/°F	BTU/hr · ft · °F	BTU/lb·°F	
SupremEX® 215XK	2.84	96	33	18.4	155[C]	0.85	0.3
	0.102	14	136	10.2	90[C]	0.20	
SupremEX 225XE / XF	2.88	115	39	16.5	155[D]	0.83	0.3
	0.104	17	161	9.2	90[D]	0.20	
SupremEX 640XA	2.90	140	48	13.3	150	0.82	0.3
	0.105	20	193	7.4	87	0.20	
AyontEX® 13	2.54	103	41	13.7	134	0.85	0.3
	0.092	15	162	7.6	77	0.20	
AyontEX 17	2.60	87	33	17.2	170	0.88	0.3
	0.094	13	134	9.6	98	0.21	
AyontEX 4632	2.70	94	35	17.1	145	0.84	0.3
	0.097	14	140	9.5	84	0.20	
AlBeMet® AM162	2.10	193	91	13.9	210	1.465	0.17
	0.076	28	368	7.7	121	0.350	
AlBeCast® 910	2.17	193	88.9	14.6	110	1.560	0.154
	0.078	28	359	8.1	64.0	0.36	
High-Purity Beryllium	1.85	303	164	11.4	216	1.93	0.01-0.08[E]
	0.067	44	657	6.3	125	0.46	
BW100®	2.89	345	-	9	275	1.05	0.26
	0.104	50.0	-	5	159	0.25	
BW3250®	2.92	345	-	9	325	1.05	0.26
	0.105	50.0	-	5	188	0.25	
Thermalox® 995	2.85	345	-	9	285	1.05	0.26
	0.103	50.0	-	5	165	0.25	
Thermalox CR	2.85	345	-	9	250	1.05	0.26
	0.103	50.0	-	5	145	0.25	
Durox® 98	3.83	351	-	8	27	0.84	0.22
	0.138	50.9	-	4	16	0.20	
Durox AL	3.94	360	-	8	30	0.84	0.22
	0.142	52.2	-	4	17	0.20	

[A] Values for these properties are given at a range of 25-100°C (77-212°F).

[B] Values are at room temperature.

[C] Estimated thermal conductivity in the T4 temper.

[D] Thermal conductivity in the T1 temper

[E] Varies by product form. Please consult Materion for more specific values.

SupremEX Lightweight Aluminum-silicon-carbide MMCs

SupremEX® MMCs are aluminum-silicon-carbide metal matrix composites, available in various material grades to address needs in a range of markets including space and defense, automotive, aerospace and consumer electronics. These composites combine the lightweight properties of aluminum with excellent strength and stiffness while being beryllium-free. SupremEX grades are available in a variety of forms, depending on grade. Mechanical properties between grades vary slightly based on heat treatments applied.

The diagram below explains the nomenclature for SupremEX composites. The first number identifies the aluminum series of the matrix alloy. The next two numbers show the volume percent SiC particle loading. The last two letters before the dash describe the SiC particle size. A table of the primary SupremEX composites is shown below. After the dash, the single letter identifies the product form: H for hot isostatic pressed (HIP), F for forged, and E for extruded. The callout after the second dash is the temper and quench.

TABLE 2.1

SupremEX Grade	Matrix Alloy	Particle Loading	SiC Particle Size
215XK	2009	15%	5 µm
225XE	2124	25%	3 µm
225XF	2124	25%	0.7 µm
640XA	6061B	40%	3 µm

Temper Designations

SupremEX temper designations follow the temper designations for heat treated aluminum alloys. The three-letter denotation after the "T[number]" temper designation refers to the quench method used: CWQ is for cold water quench and PGQ is for poly-glycol quench.

While there is overlap in temper designation naming between the two series groups, heat treatments do vary. That is, SupremEX 225XE T6 CWQ and SupremEX 640XA T6 CWQ will not undergo the same solution anneal and heat treatment process. More information on heat treating SupremEX MMCs can be found in the Processing and Fabrication Section of this Guide.

TABLE 2.2

Aluminum Alloy **Temper Designations**

Designation	Description
T1	Cooled from a high-temperature forming process and naturally aged
T4	Solution treated and naturally aged
T5	Cooled from a high-temperature forming process and age hardened by heat treatment
T6	Solution treated and age hardened
T7	Solution treated and deliberately overaged

SupremEX® 215XK is an aerospace-grade aluminum alloy (2009) reinforced with 15 vol.% silicon carbide particles. SupremEX 215XK has a naming designation of 2009/SiC/15p (5 µm). It is available in HIP'd blocks and near net shapes, forged plate and extruded bar. SupremEX 215XK has a high elongation for AlSiC MMCs with this much particulate loading. Combined with good strength properties, this grade has the highest fracture toughness of the SupremEX grades.

PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
		MPa	ksi	MPa	ksi	%
215XK Billet T4 CWQ	Typical	410	59	545	79	5
	Materion Spec Min.	340	49	480	70	3
215XK Forged Plate T4 CWQ (L- & LT- directions)	Typical	380	56	550	80	8
	Materion Spec Min.	320	49	480	70	5
215XK Extruded Bar T4 CWQ (L- direction)	Typical	410	59	600	87	9

TABLE 2.4

PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
		MPa	ksi	MPa	ksi	%
225XE Billet T4 CWQ	Typical	470	68	570	83	1.8
	Materion Spec Min.	430	62	520	75	1.3
	AMS4355 Spec Min.	430	62	470	68	1
225XE Billet T6 PGQ	Typical	400	58	535	78	2.5
	Materion Spec Min.	370	54	470	68	1.3
225XE Forged Plate T4 CWQ (L- & LT- direction)	Typical	440	64	610	89	3 - 4
	Materion Spec Min.	400	58	520	75	2
225XE Extruded Bar T6 CWQ (L- direction)	Typical	480	70	670	97	4 - 5
	AMS4379 Spec Min.	406	59	627	91	3
225XF Forged Plate T4 CWQ (L- & LT- direction)	Typical	535	78	650	94	2 - 3
225XF Extruded Bar T6 CWQ (L- direction)	Typical	620	90	745	108	3
	AMS4369 Spec Min.	580	84	700	102	2.5

SupremEX 225XE and **225XF** are aerospace-grade aluminum alloys (2124A) reinforced with 25 vol.% silicon carbide particles. SupremEX 225XE is a structural grade with moderate elastic modulus but high fatigue strength and exceptional tribological performance. SupremEX 225XF is a grade designed for higher strength, enhanced machinability and non-aggressive wear resistance.

The designations for 225XE and 225XF are 2124A/SiC/25p (3 µm) and 2124A/SiC/25p (0.7 µm), respectively. These grades are available in HIP'd blocks and near net shapes, forged plate, forged pieces and extruded bar.

TABLE 2.5

SupremEX 640XA is an aerospace-grade aluminum alloy (6061B) reinforced with 40 vol.% silicon carbide particles. Of the SupremEX grades offered, 640XA conveys the highest modulus (140 GPa) and the lowest thermal expansion coefficient (13 ppm/°C). SupremEX 640XA has a designation of 6061B SiC/40p (3 µm). SupremEX 620XF is available in HIP blocks and near net shapes as well as forged plates and pieces.

PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
		MPa	ksi	MPa	ksi	%
640XA Billet T1 / T7	Typical	390	56	460	67	1.2
640XA Billet T6 PGQ	Typical	455	66	540	78	1.4
	AMS4368 Spec Min.	400	58	500	73	1
640XA Forged Plate T1/T7 (L- & LT- direction)	Typical	360	52	480	70	2
640XA Forged Plate T6 PGQ (L- & LT- direction)	Typical	425	62	540	78	2

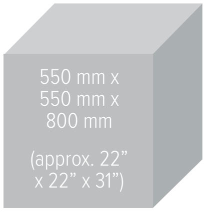
STANDARD SIZES

All SupremEX® MMCs are available as hot isostatic pressed (HIP) blocks or near net shapes derived from powder. The blocks are cut from a standard size stock block. The standard size for HIP blocks are 550 mm x 550 mm x 800 mm for rectangular blocks or 800 mm OD x 800 mm long for cylindrical or tube forms. Larger blocks can be produced if necessary. Contact Materion with questions about larger size pieces.

An advantage to powder processing is that it provides an opportunity to produce near net shape (NNS) pieces that are closer to the finish size and shape. This can reduce the input powder required to produce a volume of material. Less input powder results in improved yield and reduced machining time. Through engineering design iterations, Materion can steadily optimize the NNS parts to provide a more economical solution for the same part.

Forged plates and shapes, extrusions, and rolled sheets are also possible with most grades of SupremEX material.

Contact Materion for help developing the best solution for the application.



SupremEX Specifications and Properties

SupremEX pieces shall conform to the dimensions and dimensional tolerance established by purchase order, specification and any applicable drawings. If tolerances are not specified, the standard tolerance shall be +5 mm/-0 (+.20 in./-0) with an as-sawn surface.

Several SupremEX grades have earned SAE-AMS specifications, having been recognized as high-quality lightweight materials for use in demanding aerospace designs. These grades are shown to the right.

TABLE 2.6

SPECIFICATION	Materion	Form
AMS 4355	SupremEX 225XE	HIP shapes
AMS 4368	SupremEX 640XA	HIP shapes
AMS 4369	SupremEX 225XF	Extrusions
AMS 4379	SupremEX 225XE	Extrusions

TABLE 2.7 **Typical Mehanical and Electrical Properties** SupremEX Grades*

GRADE	Form	Heat Treatment	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Electrical Conductivity
			MPa	ksi	MPa	ksi	%	% IACS
215XK	Billet	T1	180-210	26-30	290-320	42-46	6-9	35 (T1) 27 (T4)
		T4 CWQ	410	59	545	79	5	
	Forged Plate	T4 CWQ	385	56	550	80	8	
	Extruded	T4 CWQ	410	59	600	87	9	
225XE	Billet	T1	260-310	38-45	370-410	54-59	2-4	27 (T1) 20 (T4)
		T4 CWQ	470	68	570	83	1.8	
		T6 PGQ	400	58	535	78	2.5	
	Forged Plate	T4 CWQ	440	64	610	88	3-4	
		T6 PGQ	400	58	570	83	3-4	
	Extruded Bar	T1	290-330	42-48	430-470	62-68	4-6	
		T6 CWQ	480	70	670	97	4-5	
225XF	Forged Plate	T4 CWQ	535	78	650	94	2.5	
		T6 PGQ	530	77	660	96	2.5	
	Extruded Bar	T1	440-500	64-73	550-600	80-87	3-5	
		T6 CWQ	620	90	745	108	3	
640XA	Billet	T6 CWQ	500	73	570	83	1.1	21 (T1) 18 (T6)
		T6 PGQ	455	66	540	78	1.4	
		T1 / T7	390	57	460	67	1.2	
	Forged Plate	T6 CWQ	490	71	590	86	1.7	
		T6 PGQ	425	62	540	78	2	
		T1 / T7	360	52	480	70	2	

*Data is for information purposes only; it does not constitute a guarantee. T1 mechanical properties are more variable because of the variation in cooling from hot working processes.

AyontEX Lightweight Aluminum-silicon Alloys

AyontEX® alloys are lightweight aluminum-silicon alloys designed to cater to thermal management markets such as defense, aerospace, automotive, space-based avionics and electronics, semiconductors, and consumer electronics and telecommunications. While similar to SupremEX® MMCs, AyontEX materials offer greater thermal conductivity, greater machinability and lower investment.

AyontEX 13 and **17** are based on 6063 aluminum. AyontEX temper designations follow the temper designations for heat treated aluminum alloys like SupremEX composites. Click here to revisit Table 2.2 in the SupremEX section. The three-letter denotation after the "T___" designation refers to the quench method used: CWQ is for cold water quench and PGQ is for poly-glycol quench.

Instructions for heat treating are provided in the heat treating section of this document. While there is overlap in temper designation naming between the series groups, heat treatments do vary. That is, AyontEX 13 T6 CWQ and AyontEX 4632 T6 CWQ will not undergo the same solution anneal and heat treatment process.

AyontEX 13 is a nickel-CTE-match alloy for reflective optics and is 70% lighter than nickel. The matching CTE will minimize any distortion with electroless nickel plating from temperature variation.This grade is available in billet form. Typical yield strengths and tensile strengths vary by heat treatment and are 300-325 MPa and 325-345 MPa, respectively, with an elastic modulus of 103 GPa.

PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength	
		MPa	ksi	MPa	ksi
13 Billet T1 / T7	Typical	300	44	325	47
13 Billet T6 PGQ	Typical	325	47	345	50
	Materion Spec Min.	275	40	300	44

TABLE 3.1

TABLE 3.2

PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength	
		MPa	ksi	MPa	ksi
4632 Billet T6 CWQ	Typical	390	57	450	65
	Materion Spec Min.	370	54	425	62
4632 Billet T6 PGQ	Typical	335	49	410	59
4632 Forged Plate T6 CWQ (L- and LT-directions)	Typical	360	52	435	63
4632 Extruded Bar T6 PGQ (L- direction)	Typical	330	48	415	60

AyontEX 4632 is a copper-CTE-match alloy. 4632 is the better choice between AyontEX grades when mechanical properties are critical, especially at elevated temperatures. AyontEX 4632 is available in billet, forged plate and extruded bar. Typical yield and tensile strengths vary by heat treatment and are 330-390 MPa and 410-450 MPa, respectively. AyontEX 4632 has an elastic modulus of 94 GPa.

TABLE 3.3

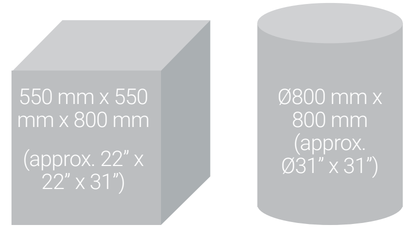
PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength	
		MPa	ksi	MPa	ksi
17 Billet T6 CWQ	Typical	300	44	355	51
17 Billet T6 PGQ	Typical	260	38	325	47
	Materion Spec Min.	235	34	300	44

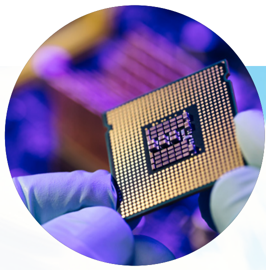
AyontEX 17 is a copper-CTE-match alloy for structural heatsinks conveying 40% of the thermal conductivity of copper at 70% density reduction. This grade is available in billet and bar form. Typical yield strengths and tensile strengths vary by heat treatment and are 260-300 MPa and 325-355 MPa, respectively. Its elastic modulus is 87 GPa.

STANDARD SIZES

AyontEX® alloys are available in a variety of forms, varying by grade. All AyontEX alloys are available as HIP billets or near net shape NNS blanks or tube forms. The standard size is the same as the standard size for SupremEX® stock blocks. Contact Materion for pieces with larger dimensions than the stocking size or for NNS blanks.

AyontEX 4632 is also available as forged plates and shapes, and extrusions. Contact Materion to help develop the best solution to the application. Our technology experts will collaborate to identify the proper manufacturing process to meet customers' unique needs.





AyontEX
Specifications and Properties

AyontEX pieces shall conform to the dimensions and dimensional tolerance established by purchase order, specification and any applicable drawings. If tolerances are not specified, the standard tolerance shall be +5 mm/-0 (+.20 in./-0) with an as-sawn surface.

TABLE 3.4

Typical Mehanical and Electrical Properties AyontEX Grades*

GRADE	Form	Heat Treatment	0.2% Offset Yield Strength		Ultimate Tensile Strength		Electrical Conductivity
			MPa	ksi	MPa	ksi	% IACS
13	Billet	T1 / T7	300	44	325	47	21 (T1) 19 (T6)
	Billet	T6 PGQ	325	47	345	50	
17	Billet	T1 / T7	170	25	240	35	34 (T1) 30 (T6)
	Billet	T6 CWQ	300	44	355	51	
	Billet	T6 PGQ	260	38	325	47	
4632	Billet	T6 CWQ	390	57	450	65	27 (T1) 24 (T6)
	Billet	T6 PGQ	335	49	410	59	
	Forged Plate (L- and LT- directions)	T6 CWQ	360	52	435	63	
	Extruded Bar (L-direction)	T1	165	24	260	38	
	Extruded Bar (L-direction)	T6 PGQ	330	48	415	60	

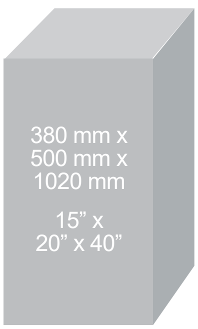
*Data is for information purposes only; it does not constitute a guarantee. T1 mechanical properties are more variable because of the variation in cooling from hot working processes.

AlBeMet and AlBeCast
Aluminum-beryllium MMCs

Materion's AlBeMet® and AlBeCast® composites are aluminum-beryllium MMCs that combine the high modulus and low-density characteristics of beryllium with the fabrication and mechanical property behavior of aluminum. AlBeMet and AlBeCast materials do not precipitation harden like many aluminum alloys and have good thermal stability over temperatures between -50°C and up to and beyond 150°C. They can be exposed to temperatures up to 490°C without altering the room temperature properties. Both composites have a modulus-to-density ratio four times that of aluminum or steel. They both have a coefficient of thermal expansion (CTE) lower than many common aluminum alloys and are a close match to the CTE of nickel plating. AlBeMet composites are commonly used in optical and structural components in aircraft, satellite and commercial applications.

AlBeMet AM162H contains 62 wt.% commercially pure beryllium and 38 wt.% commercially pure aluminum. It exhibits a typical tensile strength of 331 MPa (48 ksi), yield strength of 248 MPa (36 ksi), and elongation of 4%. AM162 can be certified to AMS 7911.

AlBeMet AM162H aluminum composite is produced via hot isostatic pressing (HIP) of powder. This process can yield a variety of round or rectangular blocks depending on the configuration that minimizes yield loss. Most HIP blocks are rectangular to improve yield when sawing rectangular pieces. The standard stock block for AlBeMet MMC is a block of 380 mm x 500 mm x 1020 mm (15 in. x 20 in. x 40 in.). The standard tolerance for sawed blocks of AlBeMet material is +6.4 mm/-0 (+.25 in./-0). It is possible to produce pieces larger than the standard stocking block or shapes other than blocks and cylinders.



AlBeMet MMC is also available in extruded rod, bar and rolled sheet. Contact Materion for extrusion sizes. Rolled sheet has been supplied as thin as 0.254 mm up to 6.35 mm (0.010 in. - 0.250 in.). Rolled sheet can be supplied to AMS 7913.

AlBeCast 910 composite is an investment cast ternary aluminum-beryllium-nickel composite with 60% beryllium. It exhibits a typical tensile strength of 193 MPa (28 ksi) and yield strength of 145 MPa (21 ksi). AlBeCast MMC can be produced to final part or near final part dimensions to minimize the input material and machining required.

TABLE 4.1

Composition Requirements AlBeMet + AlBeCast

ELEMENT	AlBeMet	AlBeCast
Aluminum, wt.%	Balance	Balance
Beryllium, wt.%	60 - 64	56 - 63
Oxygen, wt.%	1.0 max	-
Carbon, wt.%	0.1 max	-
Nickel, wt.%	0.2 max	2.4 - 3.4
Silicon, wt.%	0.2 max	0.50 max
Iron, wt.%	0.2 max	0.30 max
Other Metallics, each, wt.%	0.2 max	0.2 max
Other Metallics, total, wt.%	-	0.5 max

AlBeCast MMCs are made based on customer design. Furnace capacity and feed ratios allow for a maximum casting weight of approximately 13.6 kg (30 lb.). Cast shapes must fit within a rectangular envelope of up to approximately 500 mm x 500 mm x 400 mm (20 in. x 20 in. x 15 in.), or a cylindrical envelope up to approximately Ø600 mm x 400 mm (Ø24 in. x 15 in.).

Basic steps of investment casting AlBeCast 910 FIGURE 4.1

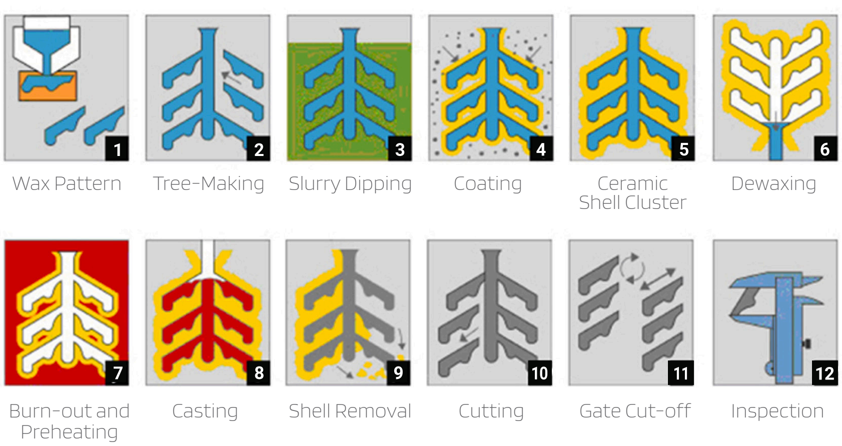


TABLE 4.2

Typical and Specification-minimum Mechanical Properties
for AlBeMet® and AlBeCast® MMCs

PRODUCT FORM	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
		MPa	ksi	MPa	ksi	% in 4 diam.
AM162 HIP	Typical	248	36	331	48	4
	AMS 7911 Spec. Min.	193	28	262	38	2
AM162 Extrusion	Typical	359 / 345[A]	52 / 50[A]	490 / 434[A]	71 / 63[A]	10 / 4[A]
	AMS 7912 Spec. Min.	276	40	400 / 345[A]	58 / 50[A]	7 / 2[A]
AM162 Rolled Sheet	Typical	324	47	427	62	7
	AMS 7913 Spec. Min.	276	40	386	56	5
AlBeCast	Typical	145	21	193	28	4.5
	Materion Spec. Min.	124	18	178	26	2

[A] Longitudinal / Transverse

AlBeMet and AlBeCast **Dimensional Specifications**

AlBeMet pieces shall conform to the dimensions and dimensional tolerance established by purchase order, specification and any applicable drawings. If tolerances are not specified, the standard tolerance shall be +6.4 mm/-0 (+.25"/-0) with an as-sawn surface.

Thickness is another design consideration. One significant advantage of AlBeCast investment casting is the ability to produce relatively thin casting wall thicknesses. Wall thickness capabilities and suggestions are outlined below.

TABLE 4.3

CASTING SIZE	Minimum Wall Thickness	Preferred Wall Thickness	Casting Size	Minimum Wall Thickness	Preferred Wall Thickness
25 - 250 mm	1.5 mm	2 - 3 mm	0 - 10 in.	0.06 in.	0.08 - 0.12 in.
250 mm and up	2.25 mm	3 - 6 mm	10 in. and up	0.09 in.	0.12 - 0.25 in.

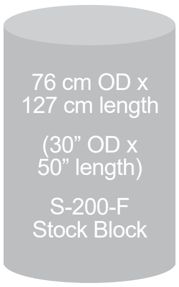
Dimensional tolerances of AlBeCast designs should be based on the maximum size of the component. Contact Materion to help design the casting.

Note: Wall thickness greater than 12.5 mm (0.500 in.) is not recommended without prior design review through Materion.

Beryllium Metals

Materion products are manufactured with distinct variations in mind to allow unique challenges to be met in various applications. Structural, raw and high-purity beryllium metals are offered in a range of grades and forms and are organized by application below.

High-stiffness, Low-density, Structure-grade Beryllium



These high-stiffness metals are provided in a variety of structural grade specifications and exhibit excellent stiffness paired with low weight. These attributes allow for weight reductions even in the durable structures needed for applications such as satellites, reconnaissance systems, semiconductor equipment, aerospace instrumentation panels and electronic-optical targeting systems.

S-200-F consists of at least 98.5% beryllium and is vacuum hot pressed. It is a versatile material used when weight and inertia factors exceed those of lower-cost aluminum. S-200F is a versatile material that has been successfully used in a wide variety of applications such as inertial guidance systems, optical substrates, spacecraft structures and small rocket nozzles. The typical billet size is approximately 76 cm OD x 127 cm length (30 in. OD x 50 in. length). It can be certified to AMS 7906 and is available in rod, bar and block forms.

S-200-FC also contains at least 98.5% beryllium and is produced from beryllium powder by cold isostatic pressing (CIP) and sintering. The primary advantage of the CIP process is the ability to produce a sintered part with features that reduce the material required to produce the part. The parts are usually smaller, under 14 kg (30 lb.) and application specific. It can be certified to AMS 7910 and is only available in near net shape.

S-200-FH also contains at least 98.5% beryllium but is hot isostatic pressed, providing isotropic properties with higher density and greater mechanical properties. It can be certified to AMS 7908 and is available in rod, bar, block or near net shape. These blocks are typically produced to a configuration that minimizes yield loss.

TABLE 4.4

Chemical Composition of Beryllium Metal Grades

MATERIAL	Symbol	I-70-H	I-220-H	S-65 S-65-H	B-26-D	S-200-F S-200-FC S-200-FH	SR-200
Beryllium	Be	99.0%	98.0%	99.2%	99.0%	98.5%	98.0%
		max. ppm	max. ppm	max. ppm	max. ppm	max. ppm	max. ppm
Aluminum	Al	700	1,000	500	900	1,000	1,600
Beryllium Oxide	BeO	7,000	22,000	9,000	5,000	15,000	20,000
Boron	B				2		
Cadmium	Cd				2		
Calcium	Ca			50	200		
Carbon	C	700	1,500	900	1,000	1,500	1,500
Chromium	Cr			100	100		
Cobalt	Co			50	10		
Copper	Cu			250	100		
Iron	Fe	1,000	1,500	800	1,000	1,300	1,800
Lead	Pb			50	20		
Lithium	Li				3		
Magnesium	Mg	700	800	100	800	800	800
Manganese	Mn			50	150		
Molybdenum	Mo			50	20		
Nickel	Ni			250	300		
Silicon	Si	700	800	450	600	600	800
Silver	Ag			50	5		
Thorium	Th						
Titanium	Ti			250			
Uranium	U			150*			
Zinc	Zn			50	200		
Zirconium	Zr			250			
Other Metallic Impurities		400	400	400		400	400

*Not specified - value determined by lot test than 400 ppm each

†Other metallic impurities comprise less

Continued: High-stiffness, Low-density, Structure-grade Beryllium

SR-200 is a 98.0% purity beryllium sheet manufactured by rolling billets of consolidated powder block. It is the form of beryllium with the highest strength, but the properties are anisotropic. The properties in plane with the sheet are higher than the through direction. It is commonly chosen for high-performance heat sinks and structural supports in military electronics and avionics systems. It is also well-suited for satellite structures. It can be certified to AMS 7902.

TABLE 4.5

Typical Minimum Mechanical And Electrical Properties:
High-purity Beryllium Materials

MATERIAL	Basis	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
		MPa	ksi	MPa	ksi	% in 4 diam.
S-200-F	Typical	262 / 269[A]	38 / 39[A]	358 / 386[A]	52 / 56[A]	3.5 / 6[A]
	AMS 7906 Spec. Min.	241	35	324	47	2.0
S-200-FC	Typical	186	27	290	42	3.9
	AMS 7910 Spec. Min.	172	35	262	38	2.0
S-200-FH	Typical	365	53	455	66	4.8
	AMS 7908 Spec. Min.	296	43	414	60	3.0
SR-200[B]	Typical	434	63	552	80	24.0
	AMS 7902 Spec. Min.	345	50	483	70	10.0
I-70-H	Typical	303	44	455	66	6.3
	Materion Spec. Min.	207	30	345	50	2.0
I-220-H	Typical	483	70	565	82	3.5
	Materion Spec. Min.	345	50	448	65	2.0 (1.0[C])
S-65	Typical	262 / 269[A]	38 / 39[A]	379 / 400[A]	55 / 58[A]	4.4 / 7.5[A]
	AMS 7904 Spec. Min.	207	30	290	42	3.0
S-65-H	Typical	290	42	448	65	6.9
	Materion Spec. Min.	207	30	345	50	2.0

[A] Longitudinal / Transverse

[B] SR-200 properties are in-plane with the sheet in the longitudinal and transverse directions.

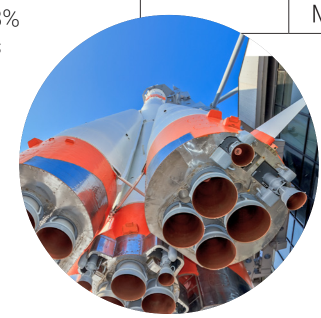
[C] Use when material consists of blanks with either (1) a calculated volume greater than 1500 cubic inches (0.0246 m^3), or (2) a major dimension greater than 20 inches (0.787 m)

Instrument-grade Beryllium for Space and Aerospace

Hot isostatically pressed (HIP) I-70-H and I-220-H grades are beryllium metals which are ideal for decreasing instrumentation weight in aircraft and satellites. Like S-200-FH, consolidation via HIP provides isotropic properties with I-70-H and I-220-H.

I-70-H grade beryllium consists of at least 99% beryllium and a maximum of 0.7% beryllium oxide. Its low oxide content makes it more easily polishable than other higher-oxide grades. It is also stable over a wide range of temperatures (-196°C to 226°C or -321°F to 440°F). I-70-H has similar properties to S-65-H.

I-220-H grade consists of at least 98% beryllium and is used in applications requiring high resistance to plastic deformation at low stress levels. This grade has the highest precision elastic limit (PEL) of the beryllium grades, but there is a trade-off with slightly lower elongation and ease of machinability. I-220-H has the highest tensile and yield strength values of the beryllium grades.

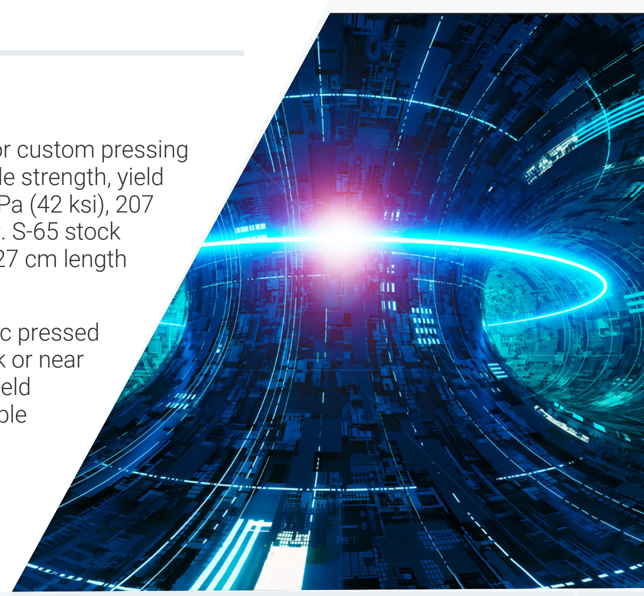


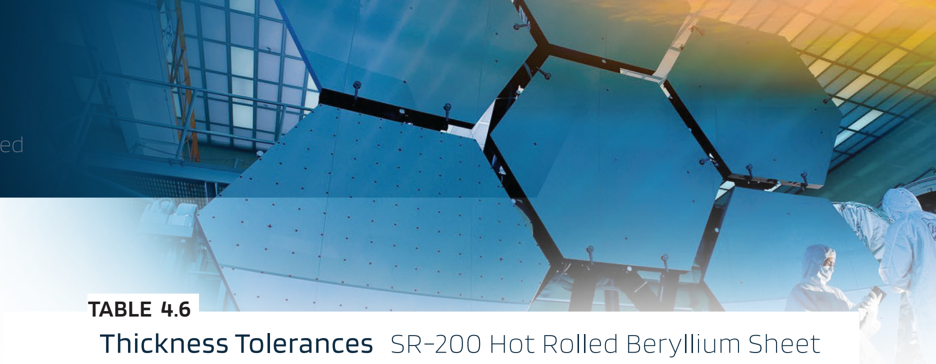
Nuclear-grade Beryllium for Reactors

S-65 and S-65-H grades are high stiffness and light weight, with the ability to maintain performance at elevated temperatures. They also exhibit properties such as high thermal conductivity under fusion conditions, high neutron flux, low neutron absorption, transparency under most forms of radiation and superior cracking resistance under high heat flux thermal cycling. These attributes allow for increased nuclear reactor efficiency and aid in the reduction of hazardous waste production.

S-65 has the lowest impurity levels of commonly made beryllium grades and is 99.2% beryllium. This grade is vacuum hot pressed and available in rod, bar or custom pressing forms. S-65 grade exhibits a tensile strength, yield strength and elongation of 290 MPa (42 ksi), 207 MPa (30 ksi), and 3%, respectively. S-65 stock blocks are typically 56 cm OD x 127 cm length (22 in. OD x 50 in. length).

S-65-H is 99.2% purity hot isostatic pressed material available in rod, bar, block or near net shape. This grade exhibits a yield strength and elongation comparable to S-65 but with an increased ultimate tensile strength of 50 ksi and isotropic properties from HIP consolidation.





B-26-D: Raw and High-purity Grade Beryllium for Defense and Industrial

B-26-D raw beryllium metal is high purity and vacuum-melted and -cast. This grade is commonly used when beryllium is required but the specific mechanical properties of the alloy are not critical. It contains a minimum of 99.0% beryllium and is available in cylindrical billet, chip and lump form.

Chips are approximately 1.0 mm x 3.2 mm x 0.127 mm (0.040 in. x 0.125 in. x 0.005 in.) thick. Chips will have a greater BeO content than lump or billet form. Lump pieces are approximately 25 cm x 25 cm x 25 cm (1 in. x 1 in. x 1 in.) maximum, with dimensions as small as 3.2 mm (0.125 in.). Crushed lump is available in smaller pieces. Please consult Materion for obtaining crushed B-26-D lump outside of the stated size range.

Beryllium is also available in ultra-high purity (UHP) with a purity of 99.99 wt% Be typically for use as a p-type dopant. This is available as irregular shaped granules approximately 1 mm (0.040”) in diameter.

Dimensional Tolerances

High-purity and non-foil materials shall conform to the dimensions and dimensional tolerance established by purchase order, specification and any applicable drawings. If tolerances are not specified, the tolerances shown in Table 4.7 shall apply.

TABLE 4.6

Thickness Tolerances SR-200 Hot Rolled Beryllium Sheet

Nominal Thickness (mm)		Standard Tolerance (mm)		Nominal Thickness (in)		Standard Tolerance (in)	
Over	Including	Plus	Minus	Over	Including	Plus	Minus
Including 0.51	0.64	0.08	0.08	Including 0.020	0.025	0.003	0.003
0.64	0.86	0.10	0.10	0.025	0.034	0.004	0.004
0.86	1.42	0.13	0.13	0.034	0.056	0.005	0.005
1.42	1.78	0.15	0.15	0.056	0.070	0.006	0.006
1.78	1.98	0.18	0.18	0.070	0.078	0.007	0.007
1.98	2.36	0.20	0.20	0.078	0.093	0.008	0.008
2.36	2.77	0.23	0.23	0.093	0.109	0.009	0.009
2.77	3.18	0.25	0.25	0.109	0.125	0.010	0.010
3.18	3.56	0.30	0.25	0.125	0.140	0.012	0.010
3.56	4.34	0.36	0.25	0.140	0.171	0.014	0.010
4.34	Up to 6.32	0.38	0.25	0.171	Up to 0.249	0.015	0.010

TABLE 4.7 Dimensional Tolerances

Diameter, Width or Thickness (mm)		Tolerance	Diameter, Width or Thickness (in)		Tolerance
Over	Including	(-/+)	Over	Including	(-/+)
0	76	-0 +0.040	0	3	-0 +1/64
76	508	-0 +1.59	3	20	-0 +1/16
508	-	-0 +6.35	20	-	-0 +1/4
Length (mm)		**Tolerance**	**Length (in)**		**Tolerance**
0	508	-0 +3.18	0	20	-0 +1/8
508	-	-0 +6.35	20	-	-0 +1/4

Beryllium Foil X-ray Foil
IF-5, PF-60, PS-200

The following materials are offered to cover a variety of purity levels for use in medical, industrial, and analytical applications. These grades are available in up to three integrity grades classified as vacuum-tight, optically-dense and as-produced.

Vacuum-tight (VT) grade has no detectable leakage through the foil when tested with a helium mass spectrometer leak detector, with sensitivity of 1x10^{-9} atm-cc/sec. Optically dense (OD, or LT for "light-tight") foil is not penetrated by visible light when tested by illuminating one side of the foil over a restricted area with a high-intensity light source and viewing from the opposite side in a darkened room.

As-produced is supplied in as-rolled condition, not inspected nor guaranteed to be vacuum-tight or optically dense. As-produced may also be referred to as filter-grade.

IF-5™ Beryllium (99.5%) very high purity foil is used for analytical applications which require the greatest image clarity with the lowest energy X-rays. It is available in three integrity grades: vacuum-tight, optically-dense and as-produced.

PF-60® Beryllium (99.0%) high purity foil is used for analytical and medical X-ray applications which require greater image clarity or utilize lower-energy X-rays. It is available in three integrity grades: vacuum-tight, optically-dense and as-produced.

PS-200® Beryllium (98.5%) standard purity foil is used for analytical and medical X-ray applications. It is available in two integrity grades: vacuum-tight and as-produced.

Chemical Composition of Beryllium Foil Grades

TABLE 5.1

MATERIAL	Symbol	IF-5	PF-60	PS-200
Beryllium	Be	99.5%	99.0%	98.5%
		ppm	ppm	ppm
Aluminum	Al	500	500	1,000
Beryllium Oxide	BeO	2,000	8,000	15,000
Boron	Be		3	†
Cadmium	Cd		2	†
Calcium	Ca	100	100	†
Carbon	C	600	600	1,500
Chromium	Cr	100	100	†
Cobalt	Co	10	10	†
Copper	Cu	100	100	†
Iron	Fe	800	800	1,300
Lead	Pb	20	20	†
Lithium	Li		3	†
Magnesium	Mg	490	490	800
Manganese	Mn	100	100	†
Molybdenum	Mo	50	20	†
Nickel	Ni	200	200	†
Silicon	Si	400	400	600
Silver	Ag	10	10	†
Thorium	Th		< 2*	-
Titanium	Ti	300	-	†
Uranium	U		25-140*	-
Zinc	Zn		-	†

*Not specified - value determined by lot test.

†Other metallic impurities comprise less than 400 ppm each as determined by normal spectrographic methods.

The table to the right outlines dimensional tolerances and geometric specifications for Materion foil products.

Dimensional Tolerance and Geometric Specifications

Pieces of foil will be cut from sheets (or entire sheets will be supplied) which have been determined to meet the specified thickness based on the sheet mean thickness measurement and standard deviation. Foils may have cosmetic imperfections and significant variation of color within each sheet. The formation of oxides is a naturally occurring process when beryllium is exposed to atmosphere.

Additional information on appropriate storage and handling can be found in the Processing and Fabrication section of this guide.

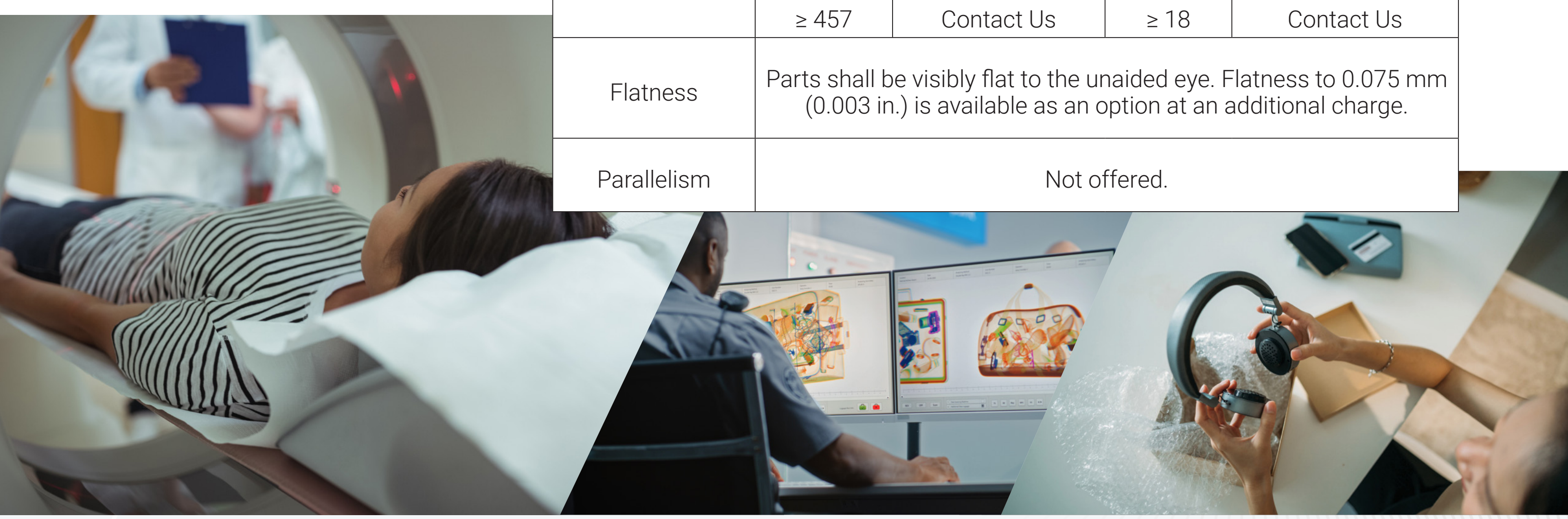
TABLE 5.2

Gauge	Tolerance		Gauge	Tolerance	Form Availability			
mm.	+ mm	- mm	in.	± in.	IF-5™	PF-60®	PS-200®	ACOUSTIC
0.025	0.005	0.005	0.001	0.0002	N/A	OD (LT) Typ. 85%	N/A	Available
0.05	0.006	0.004	0.002	0.0002	N/A	OD (LT) Typ. 90%	N/A	Available
0.075	0.009	0.006	0.003	0.0003	N/A	OD (LT) Typ. 99%	N/A	Available
0.13	0.017	0.023	0.005	0.0008	N/A	N/A	VT	N/A
0.2	0.024	0.017	0.008	0.0008	VT	VT	N/A	N/A
0.25	0.05	0.05	0.010	0.002	VT	VT	VT	N/A
0.3	0.06	0.05	0.012	0.002	VT	VT	VT	N/A
0.5	0.06	0.04	0.020	0.002	VT	VT	VT	N/A
0.8	0.06	0.04	0.032	0.002	VT	VT	VT	N/A
1	0.09	0.11	0.039	0.004	N/A	VT	VT	N/A
1.52	0.11	0.1	0.060	0.004	N/A	VT	VT	N/A
2	0.16	0.15	0.079	0.006	N/A	VT	VT	N/A
2.3	0.14	0.17	0.090	0.006	N/A	VT	VT	N/A
3.18	0.15	0.16	0.125	0.006	N/A	VT	VT	N/A

N/A: Not available Typ.: Typical leak integrity

TABLE 5.3

<table>
<tr><th rowspan="2">FEATURE</th><th>Dimension</th><th>Tolerance</th><th>Dimension</th><th>Tolerance</th></tr>
<tr><th>mm.</th><th>mm.</th><th>in.</th><th>in.</th></tr>
<tr><td rowspan="2">Diameter</td><td>≤ 152</td><td>±0.08</td><td>< 6</td><td>±0.003</td></tr>
<tr><td>> 152</td><td>±0.13</td><td>≥ 6</td><td>±0.005</td></tr>
<tr><td rowspan="3">Length / Width</td><td rowspan="2">< 457</td><td>±0.25</td><td rowspan="2">< 18</td><td>±0.01</td></tr>
<tr><td>Large-area sheets will be ±7</td><td>Large area sheets will be ±0.25</td></tr>
<tr><td>≥ 457</td><td>Contact Us</td><td>≥ 18</td><td>Contact Us</td></tr>
<tr><td>Flatness</td><td colspan="4">Parts shall be visibly flat to the unaided eye. Flatness to 0.075 mm (0.003 in.) is available as an option at an additional charge.</td></tr>
<tr><td>Parallelism</td><td colspan="4">Not offered.</td></tr>
</table>



Surface Roughness

Surface roughness is not specified. For an additional charge, the following improved surface finishes are available:

TABLE 5.4

GAUGE		Surface Finish	
mm.	in.	1.6 µm Ra / 64 µ-in Ra	0.8 µm Ra / 32 µ-in Ra
0.13	0.005	•	
0.2	0.008	•	•
0.25	0.010	•	•
0.3	0.012	•	•
0.5	0.020	•	
0.8	0.032	•	
1	0.039	•	
1.52	0.060	•	
2	0.079	•	
2.3	0.090	•	
3.18	0.125	•	

Vacuum Integrity

Foil gauges of 0.13 mm (0.005 in.) and thicker will be vacuum-tight. Vacuum-tight foil will have no detectable leakage through the foil when tested with a helium mass spectrometer leak detector calibrated to a sensitivity of $1x10^{-9}$ atm-cc/sec.

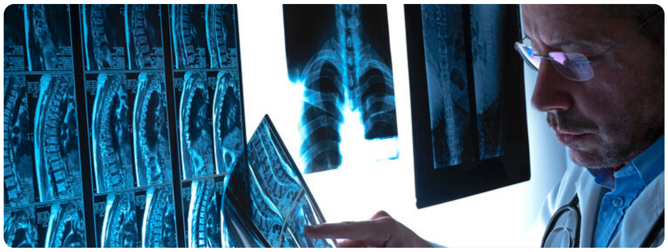
Materion's current material specifications and density validation for the bulk input beryllium ensure that foil 0.25 mm (0.010 in.) or thicker is inherently leak-tight. Orders will not be accepted which require leak tests to confirm vacuum integrity for foil at 0.25 mm (0.010 in.) and thicker.

Leak testing will be performed on gauges of 0.13 mm (0.005 in.) and 0.2 mm (0.008 in.) for PS-200® grade and 0.2 mm (0.008 in.) for PF-60® and IF-5™ grades. Such notations will be acceptable on customer drawings.

Enhanced vacuum integrity of $1x10^{-10}$ atm-cc/sec is available for an additional charge.

Formed Foil and Machined Domes for Acoustic Applications

Requests for hot-formed foil, blow-formed domes, and machined domes will be considered on a case-by-case basis. Certain designs may require updating to conform with the updated gauges and grades, as outlined in a table in a previous subsection. Go to our website to learn more about acoustic foil.



Commercial X-ray Window Assemblies for Analytical, Industrial and Medical Applications

Materion no longer offers window assemblies with foil thinner than 0.13 mm (0.005 in.). Certain designs may require updating to conform with the updated gauges and grades, **as outlined in Table 5.2**.

UHV Window Assemblies for Scientific Research

Materion no longer offers custom-made UHV window assemblies or chambers. Standard CF Flange catalog windows are offered as shown in the table below.

TABLE 5.5

Assembly Number	Flange Outside Diameter		Aperture Diameter		Minimum Foil Thickness	
	mm.	in.	mm.	in.	mm.	in.
DB133053	34	1.33	13	0.53	0.13	0.005
DB275153	70	2.75	39	1.53	0.13	0.005
DB338200	86	3.38	51	2.00	0.25	0.01
DB450277	114	4.5	70	2.77	0.25	0.01
DB600427	152	6.00	108	4.27	0.51	0.02
DB800560	203	8.00	142	5.60	0.51	0.02

Technical Ceramics: **Beryllium Oxide and Aluminum Oxide**

Materion's technical ceramics line is comprised of two product groupings, each with varying grades to meet a number of demands: beryllium oxide (BeO) and Durox® aluminum oxide (Al_2O_3).

BeO ceramics

BeO ceramics provide the second highest thermal conductivity of all electrically insulating materials, exceeded only by diamond. The BeO ceramics product line is comprised of four grades to address needs across medical, industrial and electronics markets.

Thermalox® 995 ceramic is a standard BeO, suitable for most applications where an advanced ceramic is required. Its composition is 99.5% BeO. It exhibits a flexural strength of 221 MPa and thermal conductivity of 285 W/m·K.

BW 1000® beryllium oxide offers the highest flexural strength of the listed beryllia grades at 262 MPa. It is ideal for small, fragile parts that will endure high levels of stress during the product life cycle. It has a composition of 99.5% BeO and exhibits a thermal conductivity of 275 W/m·K.

BW3250® beryllium oxide offers the highest thermal conductivity of these grades at 325 W/m·K, which is approximately eighty percent (80%) greater than common grades of aluminum nitride ceramics. It has a composition of 99.5% BeO and exhibits a flexural strength of 207 MPa.

Thermalox CR ceramic is our highest-purity BeO ceramic. At 99.7% purity, it is commonly used as a crucible material for melting other high-purity materials. It exhibits a flexural strength of 207 MPa and a thermal conductivity of 250 W/m·K.

Durox Al_2O_3 ceramics

Durox Al_2O_3 ceramics provide a cost-effective solution for applications requiring high thermal and dimensional stability and low thermal expansion within very tight tolerances. Our two Durox grades can be made in a range of shapes to match specific advanced ceramics needs. Both grades exhibit a flexural strength of 379 MPa and a hardness of 85 HR-45N.

Durox 98 alumina has a composition of 97.6% Al_2O_3 and is the most affordable alumina option for ceramic components.

Durox AL alumina has a composition of 99.8% Al_2O_3, exhibiting greater tensile strength, yield strength and thermal conductivity than Durox 98.

Ceramic Forms

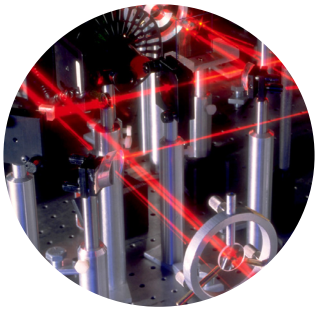
Materion BeO material is typically supplied in 20-mesh powder, dry condition, which can then be sintered into unique shapes based on customer needs.

Dry-Pressed Ceramics are pressed into the green part shape with uniaxial presses. This applies uniform pressure in one direction to form the green part before sintering. Tolerance information for dry-pressed BeO is defined in the tables below. All dimensions are interpreted per ASME Y14.5 M 1994. Tighter tolerances may be held for additional costs.

Isopressed Ceramics are pressed into the green part shape using cold isostatic pressing technology. This applies uniform pressure in all directions to form the green part before sintering. Tolerance information for isopressed BeO is defined in the tables below. All dimensions are interpreted per ASME Y14.5 M 1994. Tighter tolerances may be held for additional costs. Where tolerances are not specified, standard tolerances will be used as follows:

> Three decimal places: ±0.005" (0.127 mm)
> Two decimal places: ±0.01" (0.25 mm)
> Fractions: ±1/64" (0.396 mm)
> Angles: ±1 degree

Durox alumina ceramics can be produced in a variety of standard and custom shapes. These materials can be formed through dry-pressing and iso-pressing. For small ceramic parts, dry-pressed Durox alumina can be formed into disks, heat sinks, plates, transistor outline packages, washers and small resistor cores. For larger shapes, cold isostatic pressed Durox ceramics can be made into tubes, rods, blocks and ceramic crucibles. The dimensional tolerances for Durox® are similar to beryllium oxide, but not the same. Contact us for dimensional capabilities.



Generally, larger parts are more costly per unit area than smaller parts. Table 6.1 lists cost-effective as-fired thicknesses for several part sizes. Additional machining operations are required for designs requiring thinner substrates.

TABLE 6.1

Example	Cost-Effective As-Fired Thickness	Example	Cost-Effective As-Fired Thickness
6.35 mm square	0.635 - 0.762 mm	0.250 in. square	0.025 - 0.030 in.
19.1 mm square	0.762 - 1.02 mm	0.750 in. square	0.030 - 0.040 in.
25.4 mm square	1.02 - 1.27 mm	1 in. square	0.040 - 0.050 in.
50.8 mm square	1.02 - 1.52 mm	2 in. square	0.040 - 0.060 in.
76.2 mm square		3 in. square	
102 mm square		4 in. square	
114 mm square		4.5 in. square	

TABLE 6.2

Typical Thermal, Mechanical and Electrical Properties BeO and Al_2O_3 Grades

Material	Grade	Thermal Conductivity W/m·K	Tensile Strength		Elastic Modulus		Flexural Strength (MOR)		Dielectric Constant^	Dissipation Factor^
			MPa	ksi	GPa	10^6 psi	MPa	ksi	1 MHz	1 MHz
BeO	Thermalox 995	285	152	22.0	345	50.0	221	32.1	6.76	0.0004
	BW1000	275	172	24.9	345	50.0	262	38.0	6.76	0.0004
	BW3250	325	152	22.0	345	50.0	207	30.0	6.76	0.0004
	Thermalox CR	250	124	18.0	345	50.0	207	30.0	6.76	0.0004
Al_2O_3	Durox 98	27	152	22.0	351	50.9	379	55.0	9.5	0.0001
	Durox AL	30	276	40.0	360	52.2	379	55.0	9.7	0.0001

^Values for these properties are given at a temperature of 25°C (77°F).

Additional specification and typical property information is given above for BeO ceramics. Normal inspection is performed in accordance with ANSI/ASQ Z1.4-1993. The products produced to this specification are required to meet all values listed. The properties shown as "typical properties" of the ceramic are not evaluated on a lot-to-lot basis, unless otherwise noted. Areas not covered by this specification are covered by ASTM F-356-91.

All physical, mechanical, and electrical testing are performed at room temperature except where noted. Parts which require long firing cycles due to size have coarser grains and lower mechanical strength. Such parts typically include machining stock or parts with dimensions exceeding 25.4 mm (1 in.).

There may be variation of properties within large parts as well. Variation within large parts that is not detected through the listed tests is considered normal to the product and is not cause for return or rejection.

TABLE 6.3

Typical Properties Isopressed and Dry-Pressed BeO Parts

Property	Value	Test Method
BeO Content	99.5% min	Spectrographic by Difference
Coefficient of Thermal Expansion	(25-1000°C) 9.0 x 10^{-6}/°C	ASTM E228
Thermal Conductivity for Thermalox® 995.	285 W/mK @ 25°C	Laser Flash Method
	220 W/mK @100°C	
	180 W/mK @150°C	
	251 W/mK @ 25°C	Axial Rod Method (Ref ASTM C408)
	188 W/mK @100°C	
	150 W/mK @150°C	
Specific Heat	0.25 cal/gm C	ASTM C351
Dielectric Constant	6.73 @ 1MHz - Dry Pressed	ASTM D150
	6.76 @ 1MHz - Isopressed	
	6.67 @ 9.3GHz	ASTM D2520
Dissipation Factor	0.0004 Max @1MHz	ASTM D150
	0.0004 Max @ 9.3 GHz	ASTM D2520
Volume Resistivity	>1015 ohm-cm	ASTM D257
Dielectric Strength	¼" (6.35 mm) thick 230V/mil	ASTM D116
Density	2.85 g/cm^3, Min. Average	ASTM C373
Average Grain Size**	9-25 microns (Surface)	ASTM E112 Linear Intercept
Impenetrability, Liquid	Impervious	ASTM E165
Gas Impenetrability	10^{-8} cc/sec. Helium	He-Mass Spectrometer
Flexural Strength**	32,000 psi (221 MPa)	ASTM F417
Modulus of Elasticity	50 x 10^6 psi (345 GPa)	ASTM C623
Hardness	Rockwell 45N 60 min.	ASTM E18
Poisson's Ratio	0.26	ASTM C565
Tensile Strength	22,000 psi (152 MPa)	ASTM C565
Compressive Strength	225,000 psi (155 MPa)	ASTM C773

*Due to geometry and size of specific parts, the grain size and flexural strength may vary from nominal values.

****On the basis of bulk testing or limited sampling of material near the surface, the large parts shall meet the following properties: Bulk density: 2.85 g/cc, minimum | Grain size: 15-40 µm, average | Flexural strength: 25,000 psi, minimum average**

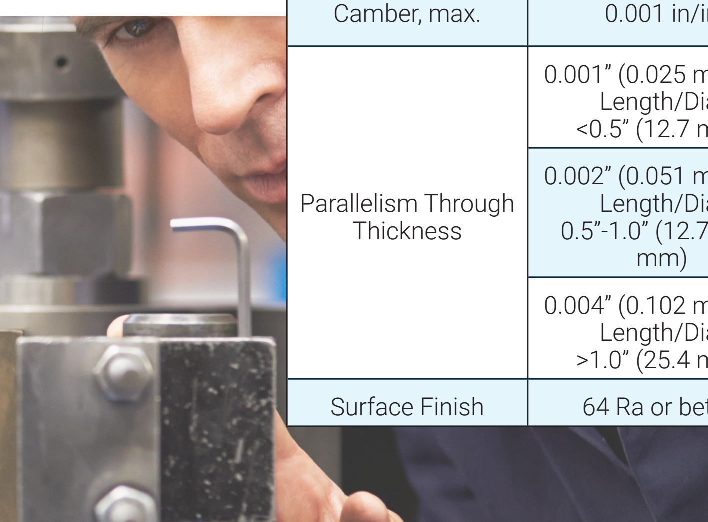
Recommended Replacements for Discontinued Materials

As new materials and alloys are developed, some alloys will be phased out or discontinued. On the next page, we have provided a brief list of recommended replacements for recently discontinued materials. Please contact us for comparative property information for replacements and their discontinued counterparts.

TABLE 6.4

Dimensional Tolerances for Dry Pressed and Iso Pressed BeO Ceramics

	DRY PRESSED		ISO PRESSED	
Dimension	As-Fired Material Tolerances	Machined After Firing	Machined Before Firing	Machined After Firing
Width & Length	±1% NLT 0.003” (0.076 mm)	±0.001” (0.025 mm)	±1% NLT 0.005” (0.127 mm)	±0.005” (0.127 mm)
Thickness	±2% NLT 0.005” (0.127 mm)	±0.001” (0.025 mm)	±1% NLT 0.005” (0.127 mm)	±0.005” (0.127 mm)
Outside Diameter	±1% NLT 0.005” (0.127 mm)	±0.001” (0.025 mm)	±1% NLT 0.005” (0.127 mm)	±0.005” (0.127 mm)
Inside Diameter	±1% NLT 0.005” (0.127 mm)	±0.001” (0.025 mm)	±1% NLT 0.003” (0.076 mm)	±0.005” (0.127 mm)
Hole Diameter	±1% NLT 0.005” (0.127 mm)	±0.001” (0.025 mm)	±1% NLT 0.005” (0.127 mm)	±0.005” (0.127 mm)
Hole Location	±0.020” (0.508 mm)	±0.005” (0.127 mm)	±0.020” (0.508 mm)	±0.010” (0.254 mm)
Concentricity	±1% NLT 0.005” (0.127 mm)	±0.005” (0.127 mm)	±1% NLT 0.005” (0.127 mm)	±0.010” (0.254 mm)
Ellipticity (round-ness)	Within dimensional tolerances		Within dimensional tolerances	
Radius	±0.010” (0.254 mm)	±0.005” (0.127 mm)	±0.010” (0.254 mm)	±0.010” (0.254 mm)
Angle, degree	±2.5	±1	±2.5	±1
Flatness (Plate)	0.004”/inch NLT 0.002” (0.051 mm) TIR	±0.001” (0.025 mm)	0.004”/inch NLT 0.002” (0.051 mm) TIR	±0.001” (0.025 mm)
Camber, max.	0.001 in/in	±0.001” (0.025 mm)	0.001 in/in	±0.005” (0.127 mm)
Parallelism Through Thickness	0.001” (0.025 mm) for Length/Dia. <0.5” (12.7 mm) 0.002” (0.051 mm) for Length/Dia. 0.5”-1.0” (12.7-25.4 mm) 0.004” (0.102 mm) for Length/Dia. >1.0” (25.4 mm)	±0.001” (0.025 mm) TIR	±0.020” (0.508 mm) TIR	±0.002” (0.051 mm) TIR
Surface Finish	64 Ra or better	64 Ra or better	125 Ra or better	64 Ra or better



*Tighter tolerances may be upheld for additional cost.
Note 1: Bars, plates, and blocks have 1/8” (3.175 mm) nominal radius.
Note 2: For extremely thin sections, some exceptions may be required.

SupremEX® 225CA can be replaced by SupremEX 225XE.

IF-1® Beryllium (99.8%) can be replaced by IF-5™ beryllium or PF-60 beryllium grades.

IS-50M® Beryllium (99.0%) can be replaced by IF-5 beryllium.

O-30H® Beryllium (99.0%) can be replaced S-65H, I-70H or S-200FH beryllium.

PF-60® Select Beryllium (99.5%) can be replaced by PF-60 beryllium.

AlBeCast® 920 can be replaced by AlBeCast 910.

E-Materials can be replaced by pure beryllium or beryllium oxide ceramic materials.

Materion Value-added Services

In addition to high-quality products, Materion provides a wide range of services to ensure the success of our materials in your application. Our highly skilled team of engineers, metallurgists and other technical staff are available to help customize the solutions that best fit given design needs. Contact us at connect@materion.com or call 1.800.375.4205 to learn more.

Fabrication Solutions

Once you have a winning design, the next step is making it a reality. Our manufacturing capabilities may provide an economical alternative to in-house fabrication of finished parts. We can assist by fabricating finished or ready-to-finish parts from our existing catalog of lightweight and high-performance materials.

After completing a producibility analysis of your drawings and specifications, guidelines can be offered for producing a quality product cost effectively and on time.

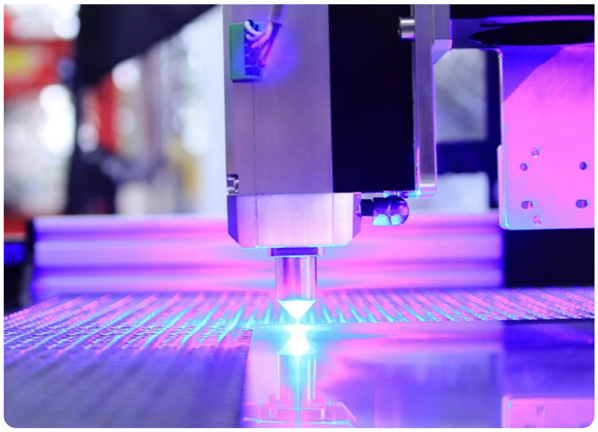
We are also developing practices and procedures for additive manufacturing of our materials. This includes determining which processes to use with these materials, finding the proper settings for these processes and creating guidelines for how to safely perform these operations.

Materion can manage the entire fabrication supply chain in order to simplify the purchasing process. This includes manufacturing the input material, overseeing the machine shops/other external vendors, managing the schedule and cost, and handling the inspection and shipment of the finished products. We operate under AS9100C, ISO 9001, ISO 14001 and ISO 17025.

Materion's engineering support and component fabrication services are trusted by leading companies worldwide in the commercial aerospace, industrial, oil and gas, alternative energy, telecom and many other markets. Committed to delivering innovative component fabrication services to meet customer needs and requirements, our expert team of engineers can help find the right fabrication solutions services and capabilities for your business. Materion is DDTC and ITAR registered and has extensive expertise in export licensing and compliance.

A combination of internal capabilities and approved external vendors are used to offer the following manufacturing and engineering capabilities:

- Conventional Machining
- Wire EDM
- Waterjet/Laser Cutting
- Open and Closed Die Forging
- Near Net Shapes
- Extruding Shapes
- Joining – Including Electron Beam, TIG Welding, Brazing
- Plating and Coatings
- Non-destructive Testing & Inspection – Radiography, Die Penetrant Inspection, Metrology, CMM
- Prototype & Technology Development



Customer Technical Service

Materion differentiates itself from other material suppliers by providing an unmatched level of customer service and support. There is a dedicated technical staff of engineers happy to assist with material selection and design, failure analysis and even educational programming.

The Customer Technical Service (CTS) team can help with material selection, processing criteria and cost considerations based on Materion's catalog of lightweight materials. Application-specific technical specialists can provide information about secondary processing of materials, including machining, heat treating, cleaning, brazing, welding, etc. CTS can also provide references for experts in plating, coating, joining, forging, extrusion, heat treating, and machining our products.

Technical staff can design a seminar to suit customers' interests and specific needs. The content is customized to address the precise aspects pertaining to their operation.

The customer support team can review designs to both verify the suitability of the design and material for the application and help identify potential problems before any parts or prototypes are fabricated. Materion can also provide material property data (stress relaxation, fatigue, etc.) and FEA input data (stress-strain curves, thermal properties, etc.).

FAILURE ANALYSIS AND RESEARCH CAPABILITIES

When something unexpectedly goes wrong, Materion's Alloy Technology Laboratory in Elmore, Ohio, is well-equipped with analytical tools to provide material evaluations and a detailed failure analysis. Please contact us to confirm equipment and analysis availability. Analytical tools include, but are not limited to, the following:

- Microscopy & Metallography
  - JEOL JSM IT-300 Scanning Electron Microscope (SEM) with Energy-Dispersive X-Ray Spectroscopy (EDS)
  - Keyence VK-X200K Confocal Violet Laser Microscope
  - HIROX Digital Microscope
  - Sample Preparation (Mounting, Grinding, Polishing, Focused Ion-Beam Milling)
- Mechanical Testing Tensile, Hardness, Fatigue, Stress Relaxation, Formability, etc.
- Physical Testing (Surface Roughness, Electrical Conductivity, Die Penetrant Inspection, etc.)
- Surface Analysis & Analytical Chemistry ICP, XRF, XRD, FTIR, GDMS, Titrations)
- Wear/Tribological Testing

In addition to these in-house capabilities, Materion has a network of external partners (test laboratories, universities, institutes) to perform other tests as required. Recommendations will be readily provided upon request.

Backed by our product stewardship organization, technical staff can provide the latest information on working safely with catalog products.

The Customer Technical Service Department may be reached at +1 800.375.4205 from the US and Canada or at +1 216.383.6800 from international locations. You can also email connect@materion.com.

Processing and Fabrication Guide

The following section contains information about designing and working with Materion's lightweight materials. Unlike previous guide sections, this section will be organized by processing and fabrication application, not by material type.

Health and Safety

Handling 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.

Before machining any parts or material containing beryllium, it is important the facility be both educated on and compliant with the OSHA Beryllium Standard. Care should be taken to secure clean, uncontaminated beryllium chips. Beryllium should not be machined until it is certain that required limits on airborne beryllium will be properly observed.

More information on the safe handling of beryllium-containing materials and compliance with the OSHA Beryllium Standard can be found at www.berylliumsafety.com.

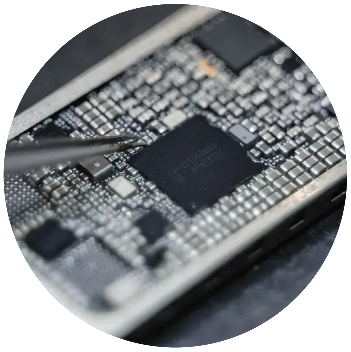
Storage, Handling and Cleaning

Materion's lightweight materials should be kept in a clean, dry, non-corrosive environment until used. Storage requirements will depend on whether the item is a block of material yet to be machined or processed, a finished machined part, or a beryllium window. When corrosive conditions are anticipated, the use of a protective coating or sealed packaging is advised. Contact Materion with questions or ideas for storage options.

Beryllium, much like aluminum, develops an adherent and protective oxide coating in air. Due to this phenomenon, 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 prevented and always followed by a rinse with deionized water and drying. Seawater is very corrosive to beryllium.

Handling

Solid pieces of Materion's lightweight materials are safe to touch. It is still a best practice to avoid touching all products with bare skin as it can contaminate or leave stains on finish surfaces. A fingerprint left on the surface will disrupt the effectiveness of the final etch or coatings. Also, machined surfaces can be sharp and handling with bare hands can lead to unnecessary scratches and cuts. We recommend handling pieces made from these materials with clean gloves appropriate for the situation.



In the case of beryllium windows, we recommend laboratory-type gloves, either latex or non-latex, and using clean vacuum tweezers. Other tools may be used but use caution with metal tools to avoid scratching the material or leaving metal marks on the material. Other sources of contamination include:

- Lint from the cleaning materials used for cleaning the beryllium windows and metal frames during lay-up, prior to brazing, or during bake-out.
- Particles floating in the air that land on the window during lay-up, prior to brazing, or during bake-out.
- Tiny droplets of saliva or perspiration falling onto the beryllium during handling. This is difficult to notice when it first happens, the stain may not appear until the moisture has dried. Wear masks when handling beryllium to help prevent this from happening.

Keep in mind perspiration and/or oil can get on the gloves by touching the skin, and this can then get transferred from the gloves to the beryllium. Change gloves often or avoid touching skin when wearing gloves to prevent this from happening. Contact Materion for insight or advice when handling beryllium windows.

Cleaning

SupremEX® and AyontEX® materials can be cleaned with solutions designed to clean aluminum. Avoid caustic or alkaline solutions or cleaners. Suitable solvents for cleaning or degreasing any of the lightweight materials include:

- Acetone
- Isopropyl Alcohol
- Methanol
- LPS ZeroTri® Heavy-Duty Degreaser

Do not use ordinary tap water on beryllium as the chlorine or other contaminants in it can damage the beryllium. Please note that even de-ionized water may become ionized over time and acetone may attract water from the atmosphere over time. Dry the beryllium quickly and thoroughly after exposure to liquids.

Special Use Cleaning Considerations

In applications – such as synchrotrons – where high powered X-rays are passing through the beryllium and one or both sides of the beryllium window are exposed to atmosphere, the emanating X-rays can cause ozone formation which can lead to the development of an oxide layer on the beryllium. This oxide build-up can be hazardous as the beryllium oxide particles are prone to become detached from the window and may be inhaled.

The build-up of ozone and subsequent formation of oxide can be prevented by continuously flowing a low-volume purge of dry nitrogen, helium, or argon across the face of the window. Ensure that any area where such a flow occurs is sufficiently ventilated to avoid the possibility of asphyxiation due to oxygen displacement. Should your window develop an oxide layer, we recommend that you do not attempt to clean it yourself as doing so can generate inhalable beryllium particles. Contact Materion for assistance.

Etching

SupremEX and AyontEX Materials

Any cleaning treatments based on an alkaline etch (e.g. caustic soda) should be avoided when working with SupremEX, and AyontEX materials. Such treatments will etch the aluminum but not the reinforcement particles. This can leave a powdery surface which can impact subsequent coating. Instead of etching, extra attention to the degreasing and/or de-smutting steps to ensure cleanliness is recommended.

Beryllium Metal

Follow all safety precautions when handling acidic solutions. Etching beryllium-containing materials will dissolve beryllium into solutions. Follow all safety precautions for handling and disposing of beryllium-containing acid and rinse solutions. If you have questions about etching any Materion materials with or without beryllium, please contact us.
Be sure to clean parts prior to etching. Acetone, isopropyl alcohol, methanol, LPS ZeroTri Degreaser, and methyl ethyl ketone (MEK) are all solvents which have successfully cleaned beryllium parts. Parts should be wiped with lint-free wipes and dried completely, leaving no residue. Be careful to avoid leaving fingerprints and other stains on a freshly cleaned surface. Lint-free gloves should be worn when handling both clean and etched parts.

Etching is performed on machined beryllium surfaces to remove the machine-damaged layer of material, twinned grain structures, which typically is 0.05 mm to 0.13 mm (0.002 in. – 0.005 in.) deep. Etching is typically performed prior to the final machining of critical dimensions. Etching is also performed to remove the recast layer after electrical discharge machining (EDM).

A common acid solution used for etching beryllium is comprised of:

- 2% nitric acid (nominal 70-71%, reagent grade)
- 2% sulfuric acid (nominal 96%, reagent grade)
- 2% hydrofluoric acid (nominal 48%; reagent grade)
- Balance de-ionized (DI) water

Other acid combinations have also successfully etched beryllium.

Heat Treating

TABLE 7.1

Heat Treatment Designations
SupremEX 640XA and AyontEX 13 and 17

Temper	Solution Anneal	Quench	Heat Treatment	Comments
T1	Air-cooled from elevated temperature forming process			Suitable for low stress parts or those subject to high temperature soak in operation. Suitable as a supply condition for material that will be further processed.
T4 CWQ	505°C (941°F) for 1 hr minimum plus 1 hr for each additional 25 mm over 25 mm, as previously detailed in "Solution Heat Treatment" section	Cold Water	Aging complete after 100 hr at room temp.	Suitable for thin section and/or symmetrical parts. Maximum properties, but some risk of distortion during quench or during subsequent machining.
T4 PGQ		20-25% Polymer Glycol	Aging complete after 100 hr at room temp.	Polymer quench reduces the risk of distortion on complex or thick section components. Lower quench rate causes some reduction in fatigue properties, depending on section.
T6 CWQ		Cold Water	150°C (302°F) for 1 hr minimum for SupremEX MMC	Suitable for thin section and/or symmetrical parts. Maximum properties, but some risk of distortion during quench or during subsequent machining. For engine components there is an option to age at 190°C (374°F)
T6 PGQ		20-25% Polymer Glycol	150°C (302°F) for 1 hr minimum for AyontEX alloy	Reduced distortion risk relative to cold water quenching.

Note: CWQ refers to Cold Water Quench; PGQ refers to Poly-Glycol Quench

SupremEX MMCs and AyontEX Alloys

SupremEX® MMCs and AyontEX® alloys respond to conventional aluminum alloy solution heat treatment, quenching and aging treatments to achieve high strength and fatigue performance. For a more in-depth explanation of heat treating, please download our SupremEX Heat Treating Tech Brief from our website.

SupremEX 2-series MMCs and AyontEX 4632

Solution heat treatment for SupremEX 2-series composites and AyontEX 4632 is performed at 505°C (941°F) for a minimum time of one hour, depending on section thickness. To avoid formation of intermetallic phases, the solidus near 530°C (986°F) should not be exceeded during heat treatment or fabrication processes. To achieve T4 or T6 tempers, pieces must be quickly quenched in cold water or a polyglycol solution before aging.

SupremEX 2-series composites will age at room temperature and reach peak strength T4 temper after 100 hours. Artificial aging of SupremEX 2 composites at 150°C (302°F) for an hour will achieve the T6 temper. This may sacrifice some strength but can increase ductility and reduce residual stress. Preferred tolerance for furnace control is ±5°C (±9°F). The tables below show typical heat treatment processes for SupremEX 2-series MMCs and heat treatment effects on 215XK and 225XE, respectively.

AyontEX 4632 must be aged at 190°C (374°F) to achieve T6 temper. Aging AyontEX 4632 at 190°C for at least one hour will achieve the T6 temper which provides peak mechanical properties. Preferred tolerance for furnace control is ±5°C (±9°F).

Solution heat treatment for SupremEX 6 series composites, AyontEX 13 and AyontEX 17 is performed at 535°C (995°F) for a minimum time of one hour, depending on section thickness. To avoid formation of intermetallic phases, the solidus at approximately 570°C (1058°F) should not be exceeded during heat treatment or fabrication processes.

SupremEX 6 composites, AyontEX 13 and AyontEX 17 must be aged at 175°C (347°F) to achieve T6 temper. Aging at 175°C for at least one hour will achieve the T6 temper which provides peak mechanical properties for these materials. Preferred tolerance for furnace control is ±5°C (±9°F).

The **Tables 7.1** and **7.2** show typical heat treatment processes as well as heat treatment effects for the designated SupremEX and AyontEX materials.

If the design requires a minimum cross section thicker than 25 mm (1 in.), then an additional hour at temperature should be added for each additional 25 mm of section thickness during the solution anneal stage.

Quench Processes

The quench medium and conditions may be selected to balance strength and residual stress. Section thickness will affect the choice of quench medium with thicker sections requiring faster quench rates to maximize strength. Section thickness should be less than 25 mm (1 in.) during quenching to achieve peak properties. Greater minimum thicknesses will make it difficult to quench fast enough to achieve peak strength.

Techniques typically employed to minimize distortion in 2024 and 6061 aluminum alloy parts can also be applied to SupremEX® products. Examples include modifications to the quench media and temperature. In addition, suitable racking, fixturing and quench orientation should be selected for the specific component geometry.

Oxidation During Heat Treatment

The oxidation of SupremEX composites and AyontEX® alloys is similar to the oxidation characteristics of the matrix aluminum alloys. The reinforcement particles are stable beyond the solidus temperature for the matrix alloys.

Stress Relief Cycles

When performing stress relief cycles on SupremEX composites and AyontEX alloys the material temper and future heat treating must be considered. Stress relief cycles performed in the T1 condition may be performed at temperatures approaching 500°C (932°F), provided the parts will be solution annealed later in the process. Care must be taken so part features do not sag due to creep. Stress relief after solution annealing to T4 or aging to T6 or T7 must be performed below the aging temperature.

It is recommended to adhere to the SupremEX machining guidelines to improve dimensional stability through heat treat and stress relief cycles.

TABLE 7.2

Heat Treatment Designations

SupremEX 2-Series and AyontEX 4632

Temper	Solution Anneal	Quench	Heat Treatment	Comments
T1	Air-cooled from elevated-temperature forming process			Suitable for low stress parts or those subject to high temperature soak in operation. Suitable as a supply condition for material that will be further processed.
T5	Cooled from an elevated-temperature forming process and artificially aged			
T6 C WQ	535°C (995°F) for 1 hour minimum plus 1 hour for each additional 25 mm over 25 mm	20-25% Polymer Glycol	Age at 175°C (347°F) for 1 hour minimum	Peak properties but typically associated with the most distortion
T6 PGQ		Cold Water	Age at 175°C (347°F) for 1 hour minimum	Near-peak properties with reduced distortion risk
T7 PGQ		20-25% Polymer Glycol	Overaged, hotter than 175°C (347°F)	Used when peak strength is not as important as other material characteristics

Beryllium Metal and Aluminum-beryllium MMCs

Beryllium metal and AlBeMet® and AlBeCast® composites are not heat treated to precipitation harden. The only heat treatment used for these materials are stress relief cycles to minimize distortion during machining.

NOTE: Beryllium part(s) will be stress relieved in a high vacuum furnace to minimize discoloration and oxidation of the machined surfaces. This method is not recommended if the finished part(s) must be completely free of discoloration. Slight discoloration is probable no matter how well the vacuum environment is maintained.

Beryllium can be stress relieved up to 788°C (1450°F). Hold at this temperature equivalent to one (1) hour/inch of cross section of part. Cool under vacuum or inert atmosphere from 788°C to 690°C (1450°F to 1274°F) at a rate not exceeding 5°C/hour (9°F/hr.). The cooling rate from 690°C to 200°C (1274°F to 392°F) should not exceed 50°C/hour (90°F/hr.). In cases of very large cross section parts, cooling should be limited to 20°C/hour (36°F/hr.).

An inert gas environment may be used below 690°C (1274°F) if desired.

AlBeMet MMC can be stress relieved up to 590°C (1100°F).

AlBeCast composite can be stress relieved up to 496°C (925°F).

TABLE 7.3

Tool Life Comparison	AyontEX 17	AyontEX 13 & 4632	SupremEX 225XF	SupremEX215XK & 225XE	SupremEX 640XA
HS Steel	✓✓	✓	X	X	XX
Carbide	✓✓✓	✓✓	✓✓	✓	X
Polycrystalline Diamond (PCD)	✓✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓

Machining

Before machining any beryllium-containing parts, it is important the facility be both educated on and compliant with the OSHA Beryllium Standard. Care should be taken to secure clean, uncontaminated beryllium chips. Beryllium should not be machined until it is certain that required limits on airborne beryllium will be properly observed.

More information on the safe handling of beryllium-containing materials and compliance with the OSHA Beryllium Standard can be found at www.berylliumsafety.com.

SupremEX MMCs and AyontEX Alloys

Conventional milling, turning and grinding techniques are suitable for both SupremEX® and AyontEX® materials. Faster aluminum cutting speeds and feed rates are preferred over slower machining rates like those used to machine titanium. Grades with lower reinforcement content and finer particles, such as 215XK, are likely to machine easier than grades with greater reinforcement content and larger particles, like 640XA.

The SiC particles in SupremEX MMCs are smaller than many AlSiC MMCs, allowing for extended tool life in precision machining operations. As AyontEX alloys have Si particle reinforcement, as opposed to SiC, they are generally less hard than SupremEX MMCs and provide reduced tool wear on machining processes.

Polycrystalline diamond (PCD) is recommended for production machining operations. High spindle speeds are preferred for PCD tooling, and these tools may require greater care on programming to avoid intermittent cutting operations. Where PCD tooling is not available, DLC coated carbide or tool steel tips can be used, but tool life may be limited depending on the grade of material.

Depth of cut should be consistent with surface quality requirements. A cutting depth up to 0.5 mm (0.020 in.) can maximize the total material removed over the life of the cutter. Mill into rather than away from edges to reduce the possibility of surface break-up on unconstrained edges. Use conventional cutting fluids as appropriate.

TABLE 7.4

Machining Recommendations for SupremEX MMCs and AyontEX Alloys*

Machining Type	Tool Material	Surface Speed	Roughing Feed	Finishing Feed
Milling	PCD	500 - 800 m/min	0.05 - 0.25 mm/tooth	0.05 - 0.25 mm/tooth
		1600 - 2600 sfpm	0.002 - 0.010 in/tooth	0.002 - 0.010 in/tooth
Turning	PCD	500 - 800 m/min	0.05 - 0.50 mm/rev	0.05 - 0.50 mm/rev
		1600 - 2600 sfpm	0.002 - 0.020 in/rev	0.002 - 0.020 in/rev
Machining Type	**Tool Material**	**Surface Speed**	**Feed**	
Drilling	PCD	approx. 113 m/min	0.020 - 0.030 mm/rev	
		approx. 371 sfpm	0.008 - 0.012 in/rev	
Machining Type	**Tool Material**	**Saw Blade Tooth Contact**	**Blade Speed**	
Sawing	Variable Pitch Ground Tooth Bi-Metal Blade	10 - 12.5 mm/tooth	40 - 50 m/min	
		2 - 2.5 teeth/in	131 - 164 sfpm	

*Note: The values shared are not specification limits. They are intended to be useful starting points based on gathered observations that may be further optimized through actual practice.

Drilling can be completed successfully for a wide range of geometries. PCD tools are recommended for drilling SupremEX and AyontEX parts, but high-quality diamond-coated tools are also acceptable. Sharp carbide tooling with TiN coating is another option, though tool life may decrease.

Conditions for thread milling, tapping and forming are dependent on the grade of material and the size of thread required.

For bandsaw cutting, bi-metal or carbide-tipped blades with tooth gap suited to cut width and surface finish requirements should be used for SupremEX and AyontEX materials. Specifically,

for AyontEX 13 carbide-tipped blades are recommended. Lubrication use is dependent on the grade being machined. High-speed dry cutting is often used for rough cutting operations, but introducing lubrication is likely to improve surface finish and lower cutting temperature.

Waterjet cutting can be used for SupremEX® and AyontEX® materials. The usual metallic materials constraints on section thickness and accuracy apply. Laser cutting can also be used. Care is required when laser cutting these materials due to the high reflectivity of the aluminum matrix materials and the potential for metal ceramic reactions in the cut zone. Parts must be heat treated to peak strength prior to final machining. Some distortion may occur during the heat treatment and quench cycle, so this should be considered and accommodated during machining.

Wire and sinker EDM and spark erosion can be applied to SupremEX and AyontEX materials – all grades are electrically conductive. There is a preference to complete wire erosion in a low residual stress heat treated condition to avoid pinching on the wire electrode. Diamond-based wheels have historically shown the longest tool life for grinding SupremEX and AyontEX materials, but SiC-based wheels may also be sufficient.

Machining AlBeMet Composite Parts

General Experience When Machining **AlBeMet Composite**

- Cutter life compared to 6061 T6 aluminum: AM162H = 75%; other AM162 = 60%.
- Aggressive chip loads will maximize material removed per cutter life cycle.
- Tungsten carbide cutting tools will outlast H.S.S. at least 3:1.
- Coolants extend cutter life. Coolants for aluminum have successfully been used.
- Peck cycles when drilling help clear chips and extend tool life.

Materion can provide a list of recommended machine shops to machine AlBeMet® or AlBeCast® composites or provide a finished component after coordinating machining and inspection.

Machining Beryllium Parts

Beryllium can be machined to intricate forms, maintaining excellent surface finishes and close tolerances when proper machining practices are followed. The machinability factor of beryllium is 55% when using AISI 1113 steel as a basis at 100%. AISI 1113 is a comparatively soft, low-carbon material with a hardness value of 80-90 Rockwell B. However, it is abrasive, producing a discontinuous chip.

Beryllium is susceptible to surface damage due to improper machining operations. Ideally, the damaged surface layer should not exceed 0.002" (50 μm) in depth; severe cases of damage may convey evidence at depths of up to 0.010" (254 μm). This damage can lend itself to a dramatic decrease in ultimate tensile strength and elongation of the affected material.

Machine damage can be mitigated and even controlled through two methods: adhering to accepted machining practices, followed by etching to remove 0.004" (102 μm) of material per side; or by utilizing heat treatments designed to anneal out twinned grain structures. See heat treating and etching sections for details.

Successful drilling involves controlling the feed rate and minimizing tool pressure through properly selected drill points. Unsuccessful drilling may be identified by the presence of laminar breakout.

Chemical milling has been successfully used in the fabrication of parts made from beryllium block, sheet extrusions and forgings. Metal can be removed over the entire surface or in select areas using masking techniques.

Electric Discharge Machining (EDM) is very effective on beryllium parts and can be used to machine intricate and irregular forms at optimal production rates. The plunge EDM process is generally carried out using copper or graphite cathode tools, which enhance metal removal rates.

Wire EDM machines can also be used to successfully cut beryllium to precise tolerance. Deionized water or dielectric oil are appropriate options for coolant and flush media. High-strength brass, molybdenum, and coated steel have all historically been used as the wire electrode.

It is imperative to use safe practices not only actively during EDM of beryllium parts, but also when cleaning and maintaining the equipment that was used to machine those parts. Ventilation equipment must be used. Do not clean equipment with air jets. The particulate may become airborne and pose a health risk if it is allowed to dry. Check out our beryllium safety guides **here** for more information on best practices for safely machining beryllium-containing materials.

Joining

Adhesive Bonding

Adhesive bonding is an acceptable way to join beryllium to itself and other metals. This 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 by far the most important.

The table below shows some of the adhesive bonding systems that have been successfully implemented. The strength values shared are intended to be useful starting points based on gathered observations and may be further confirmed through actual practice. The values are not a promise or guarantee.

TABLE 7.5

Strength of Adhesive Bonded Beryllium Joints

Adhesive System	Measured Strength	Type/Bond
EA-9309-BR127 Primer	4.7 ksi (32.4 MPa)	Lap Shear
HT-424-BR127 Primer	2.5 ksi (17.2 MPa)	Lap Shear
FM-123-BR127 Primer	3.5 ksi (24.1 MPa)	Lap Shear
Epoxy No. 206 -Grade A	3.5 ksi (24.1 MPa)	Lap Shear

Brazing and Welding

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.

Brazing has been used successfully with beryllium using a silver braze alloy with 0.50% lithium content. The brazing is done in a vacuum to prevent oxidation of the beryllium at the elevated temperature. The table below shows several joining systems which have been successfully implemented. The strength values shared are intended to be useful starting points based on gathered observations and may be further confirmed through actual practice. The values do not constitute a promise or guarantee.

TABLE 7.6

Strengths of Brazed Beryllium Joints

Joining System	Measured Shear Strength
Silver - Lithium (0.2%)	30 ksi (207 MPa)
Silver - Copper (28%)	35 ksi (241 MPa)
Easy - F10 (50 Ag, 15.5 Cu, 16.5 Zn, 18 Cd)	44 ksi (303 MPa)
Aluminum-Silicon (12%)	15 ksi (103 MPa)

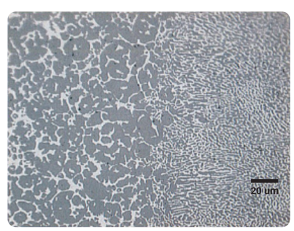
TABLE 7.7

Typical Strengths of AlBeMet 162 Joints

Joining System	Measured Strength
Epoxy Bonding BR12 7 Primer Plus Hysol High Strength Epoxy	4.0 ksi (27 MPa) (Shear)
Dip Brazing @ 580°C Braze Alloy 718	14.5 ksi (100 MPa) (Shear)
Fluxless Vacuum Brazing	10 ksi (69 MPa) (Tensile)
EB Welding	46 ksi (317 MPa) (Tensile)

AlBeMet® materials can be joined by vacuum and dip brazing methods as well. With AlBeMet composite, the joint is designed so the parent metal may break before the joint fails, unlike typical aluminum designs where the material's ductile manner causes bending before failure.

AlBeMet components can successfully be joined with electron beam welding (EBW). EBW has been successfully carried out, particularly in instrumentation assemblies, where severe structural requirements are not present. The approximate maximum joint thickness is 0.5" (12.5 mm). The images below show the hot isostatic pressed microstructure on the left and the electron beam welded microstructure on the right.

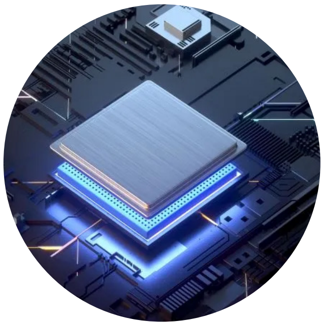


Micro-500x

The table above conveys several typical joint strengths for AlBeMet 162. The strength values shared are intended to be useful starting points based on gathered observations and may be further confirmed through actual practice. The values do not constitute a promise or guarantee.

Diffusion Bonding

Diffusion bonding beryllium to copper beryllium and beryllium to AlBeMet MMC have been successful. Contact Materion for details about this joining option.



Coatings

Most coating techniques which can be applied to aluminum alloys can also be applied to SupremEX®, AyontEX®, AlBeMet®, AlBeCast® and beryllium materials. Process parameters may need adjustment. Final coating thickness and/or appearance may vary from conventional aluminum.

The higher stiffness of Materion's lightweight metals and composites offers an advantage for most coatings by reducing flexural delamination during use. Once coating stabilizes the machined surfaces, coated parts may be stored for months if necessary. Use a simple alcohol wipe to remove any dust or fingerprints prior to additional assembly suffices.

The coatings that have been successfully applied to Materion's lightweight materials are shown in the table on this page. Note that just because a check mark is not in a box does not necessarily mean that coating cannot be applied. In some cases the combination has not been requested or tested. Some coatings are more easily applied on top of another coating, like gold on electroless nickel or hard anodize on aluminum plating.

Materion can provide contact information for vendors that can apply various coatings to Materion materials. Please contact us for more information on coating options.

TABLE 7.8

Types of Coatings Applied to Materion's Lightweight Materials

Coating	Coating Type	Has been successfully applied on:				
		SupremEX	AyontEX	AlBeMet	AlBeCast	Beryllium
Passivation	Conversion Coat	✓	✓	✓	✓	✓
Anodization	Chromic Anodize Type I	✓	✓		✓	✓
	Sulfuric Anodize Type II	✓	✓			
	Hard Anodize Type III	✓	✓		✓	
Plating	Electrolytic Nickel	✓	✓	✓		✓
	Electroless Nickel	✓	✓	✓	✓	✓
	Aluminum Plate	✓	✓	✓	✓	
PVD	Various	✓				✓
Ceramic	Plasma Electrolytic Oxidation (PEO)	✓				✓
Paints or Dyes	Epoxy Primer e.g. BR® 127	✓	✓	✓	✓	✓
	Organic/Inorganic Finish	✓		✓	✓	
	Powder Coating	✓		✓	✓	✓

Passivation

Passivation creates a passive oxide layer on the surface of a material to prevent further corrosion. Chromate conversion coatings are typically applied to aluminum alloys. The process involves the passivation of metals by an immersion bath process. The bath solution reacts with oxides on the metal surface to form a protective layer.

Chromate conversion coatings can be applied to SupremEX, AyontEX, AlBeMet, AlBeCast and beryllium parts. Examples of appropriate products for SupremEX MMC are Alodine® 1200/Alocrom 1200, Iridite®, and SurTec 650. Enhanced resistance of salt spray and high temperature oxidation are provided to beryllium, AlBeMet and AlBeCast parts by chromate conversion coatings developed for aluminum (e.g., Iridite or Alodine). These coatings are formulated and applied following the instructions for use on aluminum.

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 precise instrumentation. No measurable change in dimension or appearance results with the use of the treatment. Materion performs Berylcoat D coating on beryllium metal in-house and supplies the Berylcoat D solution to customers that choose to apply the coating themselves.

Anodizing

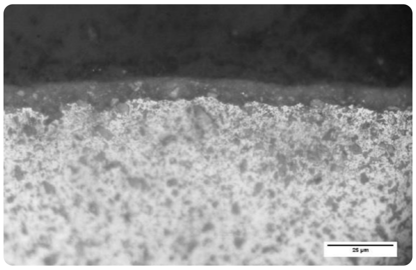
Anodizing is a process which takes advantage of the natural oxide layer on the surface of a material to increase resistance to corrosion and wear. Soft or cosmetic anodizing is a process where the oxide layer is grown so that it has tubular porosity and can be dyed to change color. Hard anodizing has a slightly denser coating, greater thickness and greater abrasion resistance than soft anodizing. While it is still possible to dye hard anodized coatings, it can be more challenging.

In general terms, aluminum-based materials with low concentrations of alloying elements anodize better than alloys with high concentrations. Thereby, the alloy family affects anodizing performance. In general, 6-series SupremEX® MMC and AyontEX® 13 and AyontEX 17 alloys (low galvanic potential between Al and Mg/Si) anodize better than 2-series SupremEX MMC and AyontEX 4632 alloy(high galvanic potential between Al and Cu). That is not to say that anodization of 2-series SupremEX and AyontEX 4632 materials is difficult. In fact, there is significant experience of anodizing the SupremEX 225XE grade. As with conventional aluminum alloys, good electrical contact and process cleanliness is key to cosmetic anodizing.

Most of the common best practices for anodizing apply to SupremEX and AyontEX materials (e.g. clean parts, solutions, rinse water, and maintaining good electrical contacts). Some specific advice when anodizing SupremEX MMC:

- Do not use a caustic etch. It can cause selective etching of SupremEX and AyontEX materials, leaving reinforcement and/or intermetallic phases on the surface which can interfere with anodic film growth.
- De-smut in a de-smut solution designed for silicon-based intermetallics.
- Dyeing options/colors on SupremEX materials might be reduced compared to normal aluminum alloys.

The anodized layer produced using this approach tends to be rich in ceramic and light grey in color. In the case of SupremEX composite, this color comes from the SiC particles that are transferred from the aluminum to the anodized layer during growth of the anodic film. See the example image on this page.



Micrograph of sulfuric anodized SupremEX 225XE showing an 8–10 micron anodized layer.

Chromic black or "black" anodization of beryllium has been 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.

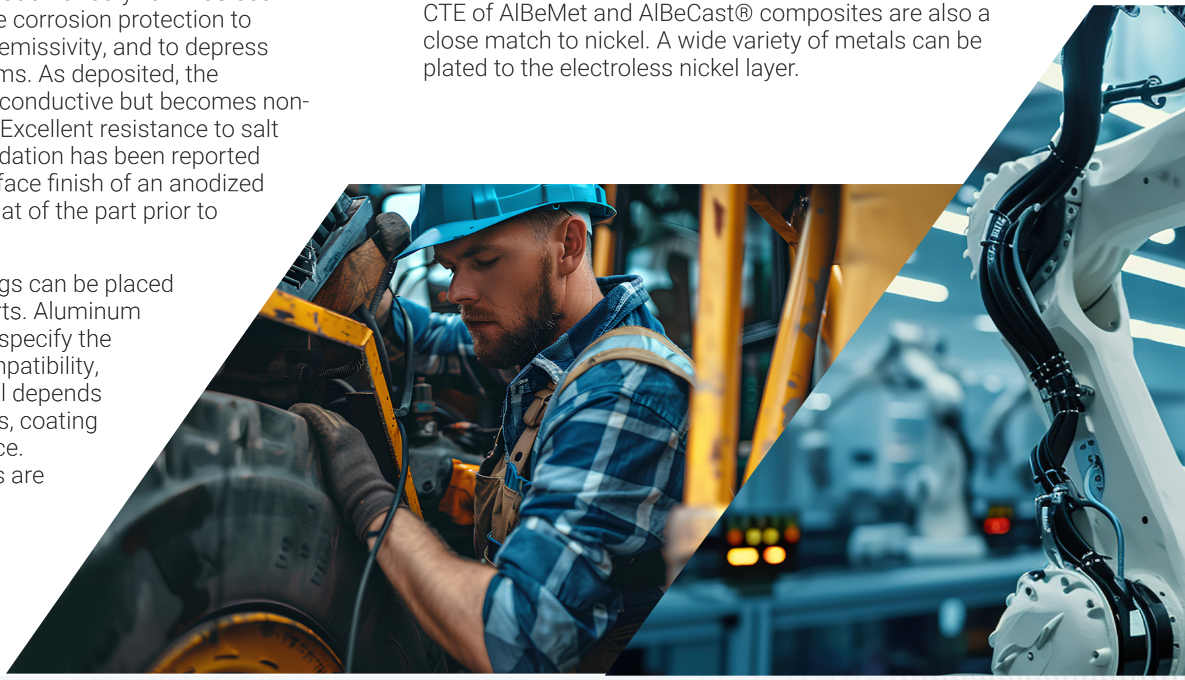
Protective and cosmetic coatings can be placed on AlBeMet® and AlBeCast® parts. Aluminum industry standards are used to specify the coating. In addition to alloy compatibility, successful coating of any metal depends on variables such as cleanliness, coating source and processing sequence. AlBeMet and AlBeCast surfaces are approximately 70% beryllium and 30% aluminum so the anodizing source may need to experiment to develop the best practice. Test coupons should be used for any new coating and/or coating source.

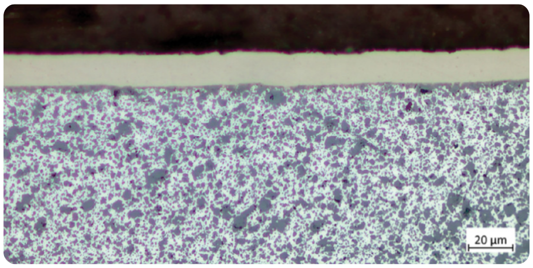
Plating

Plating is a process which involves coating a metal on another metal surface using chemical or electrochemical deposition. Plating functions to increase resistance to wear, corrosion, reflectivity, or as a foundation layer for subsequent layers of plating.

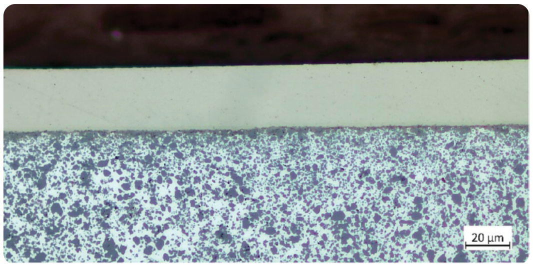
Electroless and electrolytic nickel plating has been successfully plated on SupremEX composite and AyontEX 13 alloy. SupremEX 640XA, AyontEX 13 and nickel all have a similar CTE near 13 ppm/°C. This renders these grades particularly suitable for applications requiring Ni plating, as the close CTE-match will minimize thermal mismatch strains during thermal cycling in operation, improving performance and extending life. Example images of Ni plated AyontEX 13 are given on the next page.

Electroless nickel (EN) plating has been used extensively with beryllium and AlBeMet® materials. This is especially true in the optics field where the nickel plate is utilized in developing the optical figure and final polish of beryllium mirrors. Like AyontEX® 13 and SupremEX® 640XA, the CTE of AlBeMet and AlBeCast® composites are also a close match to nickel. A wide variety of metals can be plated to the electroless nickel layer.





Micrograph of electrolytic Ni plated AyontEX 13



Micrograph of electroless Ni plated AyontEX 13

Physical Vapor Deposition

Physical vapor deposition (PVD) describes a variety of vacuum deposition methods which can be used to produce thin films and coatings on many different types of materials. PVD can be performed directly to the base metal or is sometimes applied to another coating. The beryllium mirrors on the James Webb Space Telescope were first electroless nickel coated and then PVD coated with gold. SupremEX MMC has been successfully PVD coated with titanium nitride (TiN) and chromium nitride (CrN).

Epoxy Primer

BR® 127 epoxy primer is used extensively in the aerospace industry as a corrosion-inhibiting coating for a variety of aluminum alloys. It has been successfully applied to AlBeMet and AlBeCast composites as well as pure beryllium grades.

Metallization of Ceramics

Metallization coatings are typically applied to ceramic materials. This thin metallic layer bonded to the surface allows for subsequent electroplating of other metallic coatings. MoMn is the most used metallization coating for beryllium oxide.

Please reach out to us for contact information for vendors that can apply various coatings to Materion materials.

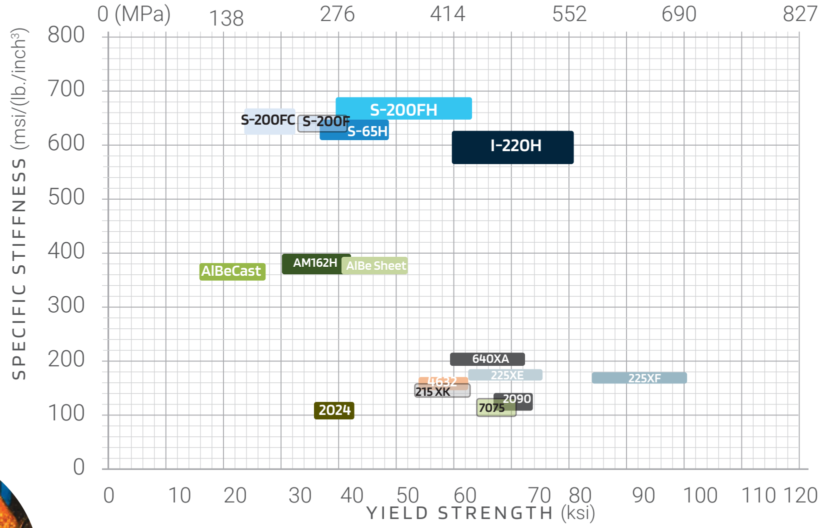
Other Attributes and Application Engineering Data

Strength and Specific Stiffness

All of Materion's lightweight materials have a unique combination of high stiffness and low density. This allows them to excel in airborne applications for structures and optics.

TABLE 8.1

Yield Strength vs. **Specific Stiffness**



Fatigue Strength

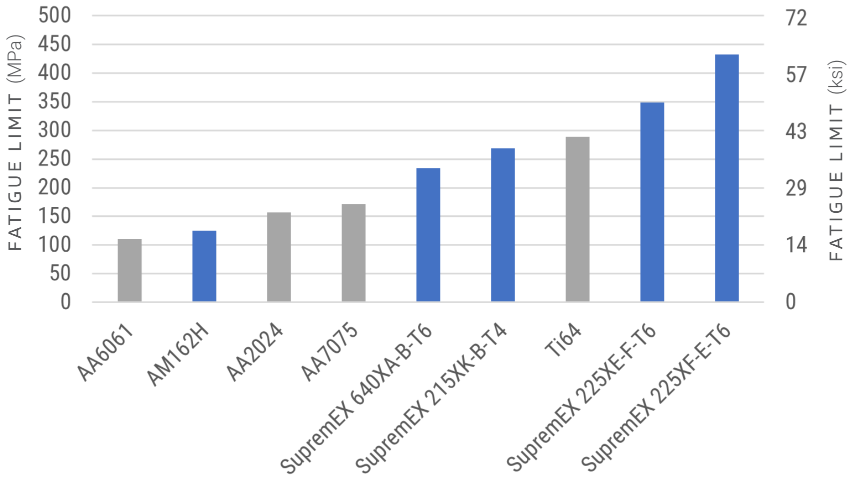
The fatigue properties of SupremEX® MMCs have been evaluated across many product forms and test conditions. A summary is provided on this page. Similar to AlBeMet® composite, SupremEX MMCs typically display a high cycle fatigue limit only slightly below their RT yield strength. The highly refined and homogenous microstructure of SupremEX composite provides an increase in fatigue strength of up to 3x that of conventional aluminum alloy systems, depending on the grade and product form.

Please contact Materion for the fatigue data of any of our materials. Some fatigue data for AlBeMet MMC and S-200-F beryllium grades are available through the Metallic Materials Properties Development and Standardization (MMPDS Handbook). Materion's lightweight materials, along with Alloy 25 copper-beryllium and ToughMet® 3 copper-nickel-tin alloy can be found in Chapter 7 of the MMPDS Handbook.

TABLE 8.2

Room Temeprature **Fatigue Limit**

(R=-1.0, Kt=1) @10^7 Cycles



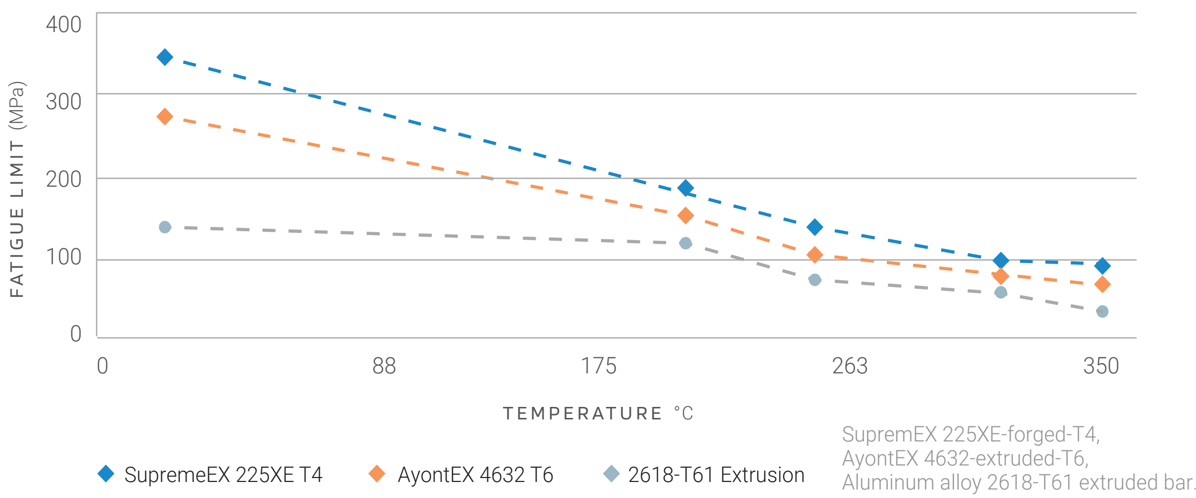
S-N Axial Fatigue Curves for Unnotched SupremEX and AlBeMet MMCs (R=0.1 per ASTM E466)

S-N Rotating Bend Fatigue Curves for Unnotched SupremEX MMCs (R=-1)

Fatigue Strength

The elevated temperature fatigue performance of SupremEX® MMCs and AyontEX® 4632 alloy have been characterized also. This chart provides a summary of the effect on temperature of the high cycle fatigue limit of these materials in comparison to AA2618.

TABLE 8.3
SupremEX 225XE v. AyontEX 4632 v. AA2618,
Rotating Bend 10^7 Cycle Fatigue Limit (R=−1, Kt=1) Versus Temperature



SupremEX 225XE-forged-T4,
AyontEX 4632-extruded-T6,
Aluminum alloy 2618-T61 extruded bar.

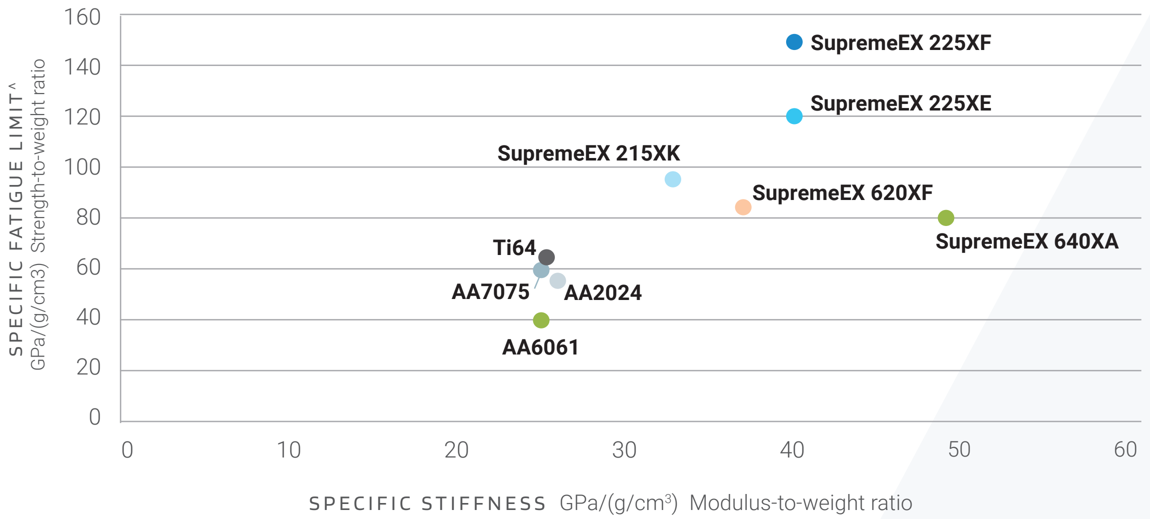
Specific Stiffness and Fatigue

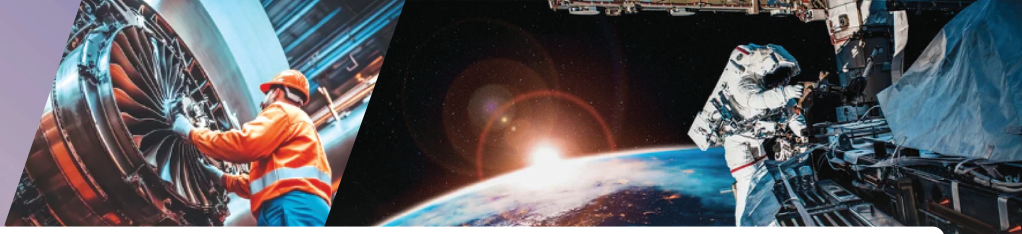
The graph to the right shows the specific stiffness and the specific fatigue limit for various SupremEX grades and common aerospace alloys.

SupremEX grades are 215XK-T4 and 225XE-T6 forged plate, 225XF-T6 extrusions, and 640XA-T6 HIP'd billet.

Aluminum alloys 2024-T4, 6061-T6, 7075-T6, and titanium alloy Ti6Al4V are bar.

TABLE 8.4
Specific Stiffness and Specific Fatigue
SupremEX Grades and Common Aerospace Alloys
At 10^7 cycles, R=−1 and Kt=1.

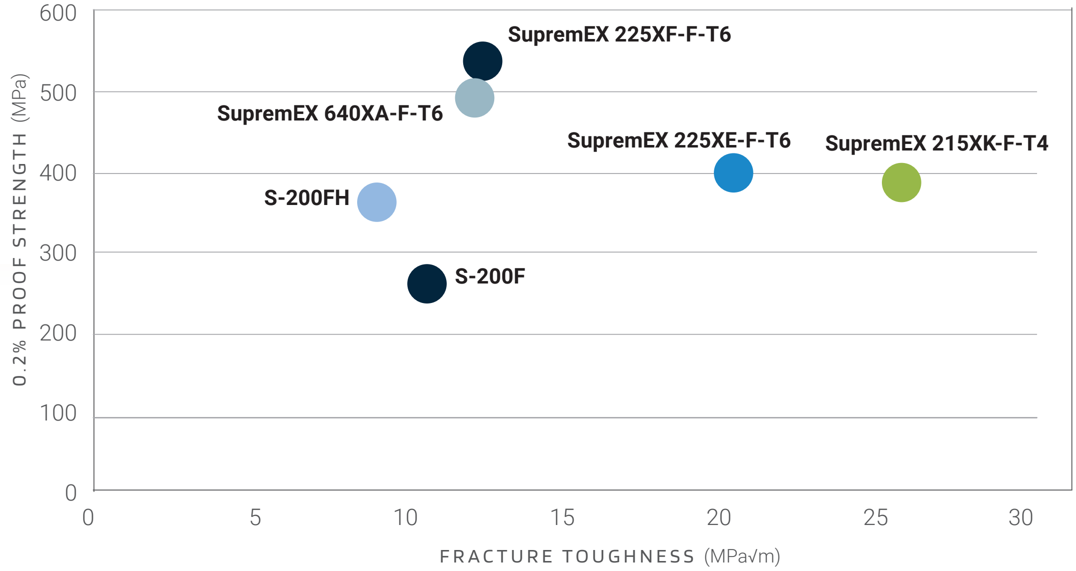




Fracture Toughness

The fracture toughness for SupremEX® MMCs, S-200-F beryllium, and S-200-FH beryllium is depicted by this chart.

TABLE 8.5 **Fracture Toughness** of Forged SupremEX Plate and As-pressed Berylium Materials

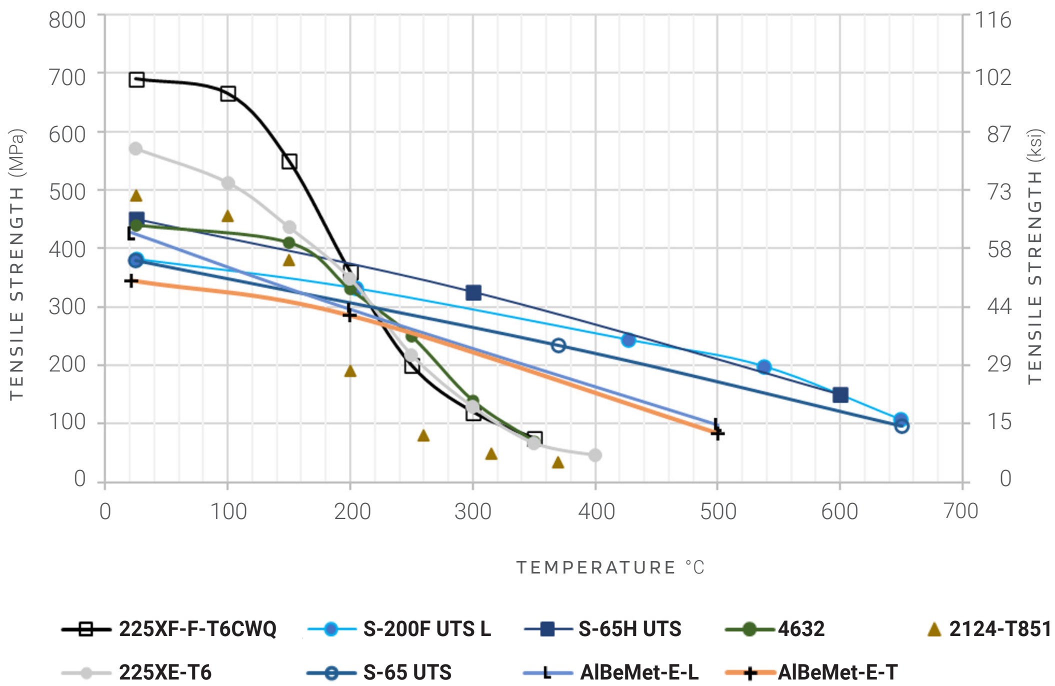


Elevated Temperature Properties

SupremEX MMCs provide an improvement in tensile strength in comparison to conventional aluminum alloys at elevated temperatures. The strength of both conventional aluminum alloys and MMCs decreases rapidly in the 180°C to 250°C (356°F to 482°F) range, as the aluminum phase experiences over-aging.

Extruded AlBeMet® composite exhibits a strength of 100 MPa (14.5 ksi) at 500°C. Beryllium exhibits a strength near 200 MPa (29 ksi) at 500°C. The strength of S-65, S-65-H, and S-200-F converge to approximately 100 MPa (14.5 ksi) at 650°C.

TABLE 8.6 **Elevated Temperature Strength Properties** for Several Materion Lightweight Materials

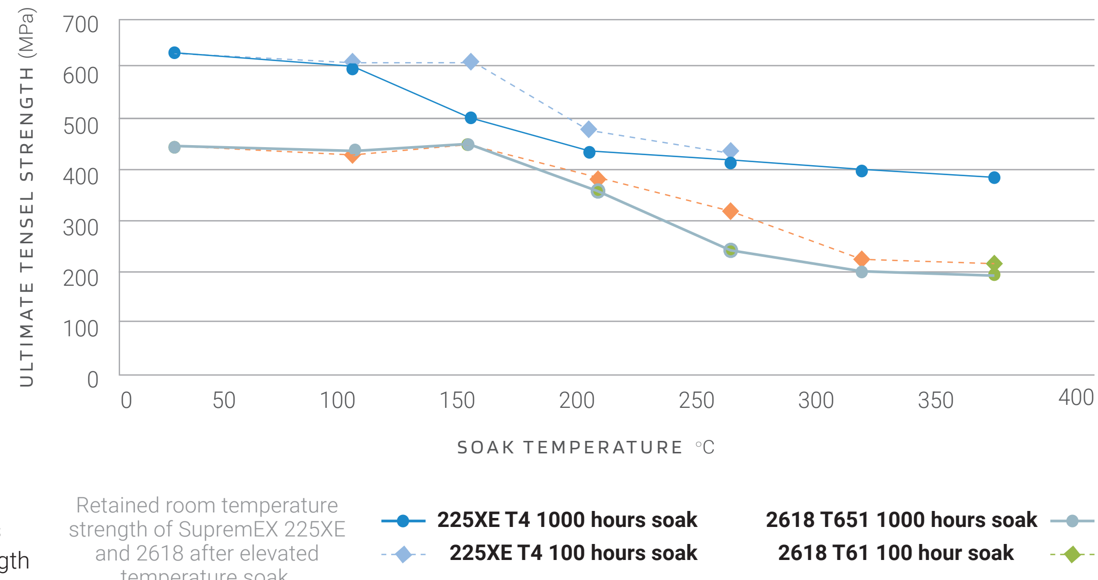


* Aluminum alloy 2124-T851 included for comparison

Retained Room Temperature Strength

SupremEX® MMC displays superior retained room temperature strength and strength at temperature, as the chart to the right highlights. Note the aluminum alloy and MMC strength should converge as temperature approaches the matrix alloy melting temperature.

TABLE 8.7



Retained room temperature strength of SupremEX 225XE and 2618 after elevated temperature soak.

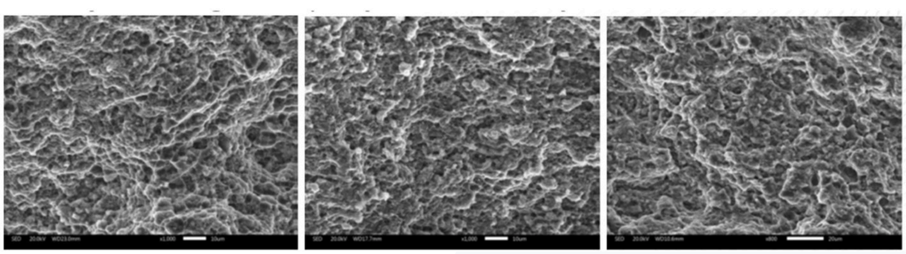
AlBeMet® composite retains the room temperature strength after exposure for 24 hours at the stress relief temperature of 1100°F (593°C). AlBeCast® MMC retains the room temperature strength after exposure to 925°F (496°C). Beryllium grades retain room temperature strength after exposure to stress relief treatments up to 1450°F (788°C).

Susceptibility to Hydrogen

The susceptibility of SupremEX composite to hydrogen embrittlement following H_2 exposure at elevated temperature has also been investigated. Pressurized hydrogen loading of SupremEX 225CA was carried out at 300°C and 275 bar over a period of 21 days. Following this, thermal desorption analysis found the SupremEX material did not absorb any measurable level of hydrogen (<0.001 ppm). In parallel and to act as a reference, samples were prepared which were only heat treated (in the same way), without hydrogen loading.

Slow strain rate tensile tests (SSRT) were performed on all three sample conditions (delivery condition, only heat treated, H_2-loaded), at a strain rate of 0.1 mm/min. As expected, there was a significant influence of temperature on mechanical properties. However, the H_2-loading resulted in no additional change in mechanical properties, as shown in the photos on this page. The fracture surface analysis also did not show any particular differences between the fracture behavior of the different conditions. In each case, a fine-facetted, ductile honeycomb fracture was observed and no signs of hydrogen embrittlement (according to hydrogen-enhanced localized plasticity, HELP) could be detected. SupremEX MMC can thereby be understood to have stable behavior towards hydrogen and can be considered as immune.

Hydrogen susceptibility into aluminum and beryllium has been studied and some data is available.



Delivery Condition | Only Heat Treated | H_2-loaded

Summary of elevated temperature hydrogen exposure testing on SupremEX 225CA.

Thermal Conductivity and Specific Heat Capacity

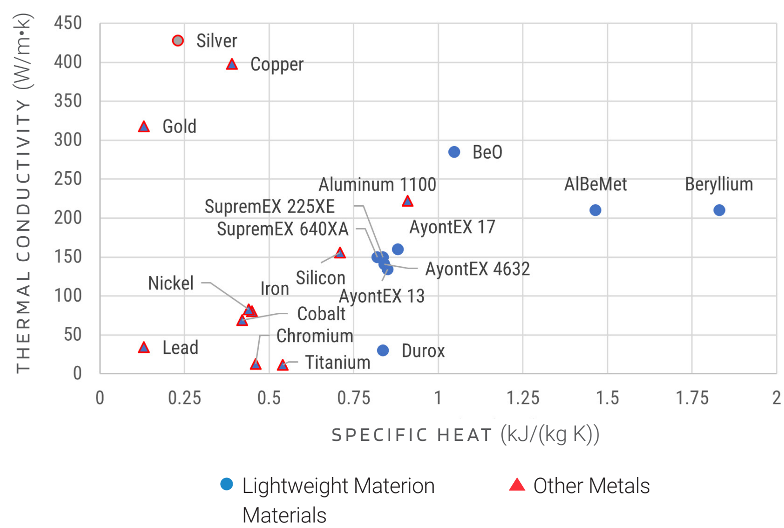
Thermal management using lightweight substrates and heat sinks for electronic assemblies are key material challenges for increasing power density requirements in both hand-held and weight-critical components.

Properties like thermal conductivity, specific heat capacity and density factor into the decision. Another challenge can be minimizing movement and flexure that could lead to a circuit fracture or open circuit failure. Materials with a high modulus reduce the flexing and movement that can lead to these failures. Thermal fatigue can often occur in devices that are cyclically turned on and off if components do not have matched coefficients of thermal expansion (CTE).

Materion's low-density materials offer unique combinations of thermal conductivity, specific heat, modulus, CTE and operating temperature for solving problems in applications that require dissipating heat energy.

TABLE 8.8

Thermal Conductivity and Specific Heat Capacity



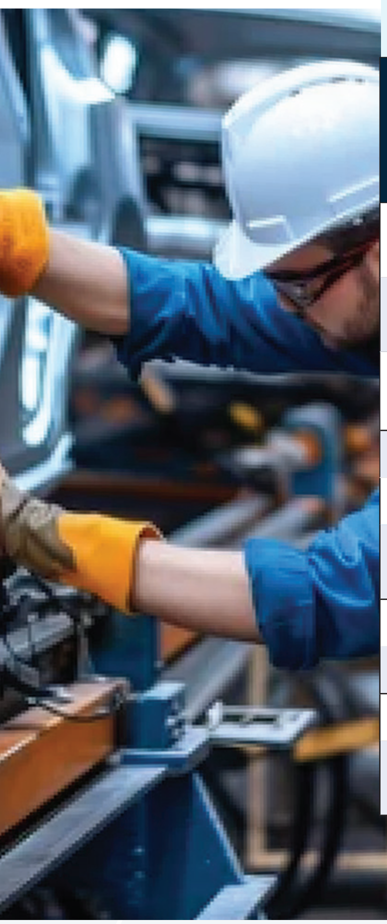


TABLE 8.9

Heat Sink Related Properties

PRODUCT	Density		Modulus		Thermal Conductivity		Specific Heat Capacity		CTE		Solidus	
	g/cc	lb./in³	GPa	msi	w/m·K	BTU/ hr·ft·°F	J/g·C	BTU/ lb.·°F	ppm/ °C	ppm/ °F	°C	°F
SupremEX® 215XK	2.84	0.102	94	14	155	90	0.848	0.20	18.5	10.3	548	1018
SupremEX 225XE/F	2.88	0.104	115	17	150	87	0.836	0.20	16.1	8.9	548	1018
SupremEX 640XA	2.9	0.105	140	20	130	75	0.82	0.20	13	7.2	570	1058
AyontEX® 13	2.54	0.092	103	15	134	77	0.85	0.20	13.7	7.6	570	1058
AyontEX 17	2.6	0.094	87	13	170	98	0.88	0.21	17.2	9.6	570	1058
AyontEX 4632	2.7	0.097	94	14	145	84	0.84	0.200	17.1	9.5	548	1018
AlBeMet®	2.1	0.076	193	28	210	121	1.465	0.350	13.9	7.7	644[A]	1191[A]
AlBeCast®	2.17	0.078	193	28	110	64	1.56	0.36	14.6	8.1	644[A]	1191[A]
Beryllium	1.85	0.067	303	44	216	125	1.93	0.46	11.4	6.3	1285	2345
Beryllium Oxide	2.85	0.103	345	50	285	165	1.05	0.25	9	5	2578	4672

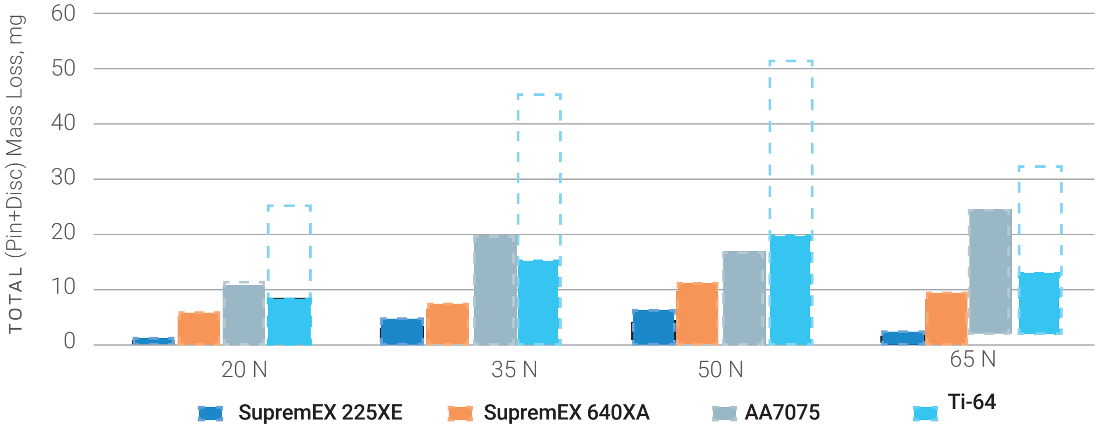
[A]Beryllium-aluminum eutectic temperature J.L. Murray and D.J. Kahan.

Wear Properties

The wear performance of SupremEX® MMCs has been characterized in accordance to ASTM G99, highlighting the non-aggressive and low-friction wear resistance of the materials. Pin on disc testing using a 4340 steel pin with a ground finish was carried out on SupremEX 225XE, SupremEX 640XA, aluminum alloy 7075 and titanium alloy Ti64. Multiple loading and sliding distance conditions were tested as follows: 20 N for 0.3 km, 35N for 0.3 km, 50 N for 0.3 km and 65 N for 0.15 km. As can be derived from the below chart, it was found that the SupremEX discs exhibited the least wear for all conditions. In addition, significantly lower wear on the steel pin was observed with the SupremEX samples compared to Ti64, highlighting the non-aggressive nature of SupremEX MMC in a wear/fretting scenario.

Coefficient of friction was also measured according to ASTM G99, with the results shown below. Here, the lower static and dynamic coefficient of friction of SupremEX composite versus common aluminum and titanium alloys can be seen.

TABLE 8.11



Comparison of pin on disc wear results for SupremEX 225XE and 640XA, aluminum alloy 7075 and titanium alloy Ti-64. Pin material = 4340 steel. Solid bar = Disc mass loss. Dashed bar = Pin mass loss.

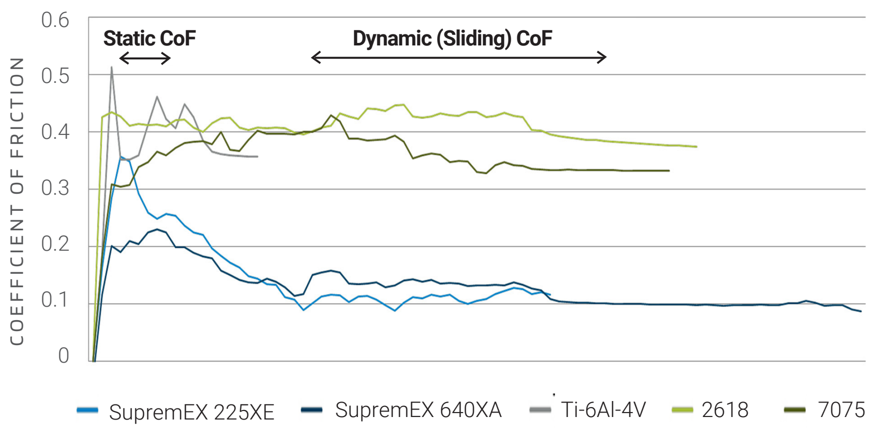
Corrosion Resistance

SupremEX 640XA and 225XE MMCs have both passed the critical ESA SCC test (ECSS-Q-70-37A). SupremEX 640XA and 225XE metal matrix composites were both classed grade 1 SCC. Read more in the Coatings section.

Conventional coating technologies such as chromate conversion, anodizing, electroplating and plasma electrolytic oxidation can all be applied to these materials to provide enhanced corrosion protection. Read more in the Coatings section.

AlBeMet® 162 sheet and extruded products have both been tested for stress corrosion cracking by Materion and independent laboratories like the European Space Agency (ESTEC) materials laboratory. The testing at Materion consisted of using the ASTM G38-73 test procedure, "C-Ring Stress Corrosion Testing", and subjecting the specimens to 30 days in a 3.5% sodium chloride (NaCl) solution. The testing at ESTEC used ASTM E8-M subsize specimens which were subjected to 75% of the 0.2% proof stress (yield strength) and immersed in 3.5% NaCl solution for 10 minutes and dried for 50 minutes. Both sets of tests demonstrated that AlBeMet 162 sheet and extrusions are not susceptible to stress corrosion cracking. Results are shared in the table to the right.

TABLE 8.12



Comparison of coefficient of friction for SupremEX 225XE and 640XA, aluminum alloy 7075 and titanium alloy Ti-64.

TABLE 8.13 **ESTEC Stress Corrosion Cracking** Test Results

Specimen	Stress During SCC test	UTS	Yield Strength	Elongation % after Fracture	E	Time to Failure
	MPa	MPa	MPa		GPa	Hours
AM162RL	291	425.1	411	1.0	198.0	No failure
AM162RT	291	408.1	403	1.0	244.6	No failure
Avg	291	416.6	407	1.0	221.3	No failure

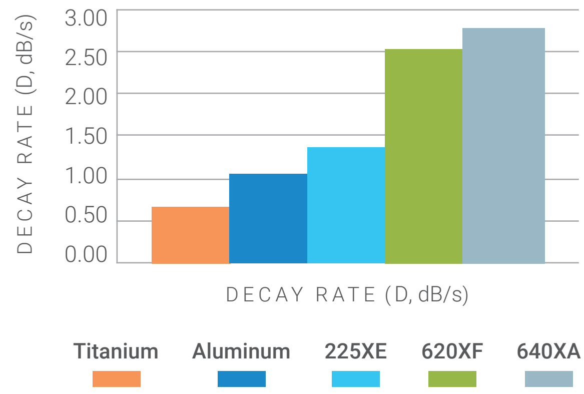
Note: ESTEC/ESA has given its approval for the use of AlBeMet 162 on satellite structures for European spacecraft

Acoustic and Structural Damping Properties

SupremEX® materials exhibit excellent acoustic and mechanical damping which can be advantageous for several applications including vibration reduction during take-off and reducing line-of-sight jitter in precision optics. This graph shows how the acoustic damping of SupremEX materials compares to that of other materials – **SupremEX** MMCs show increased decay rates (improved damping) compared to aluminum and titanium alloys.

AlBeMet® and AlBeCast® composites as well as beryllium provide excellent vibration damping properties. This is an added benefit for optical and high-speed precision assembly equipment.

CHART 9.1



Vibration Loss Factor

Vibrational characteristics are important for system designs that cannot afford long resonant or slow sound attenuation. Examples of systems that improve with higher noise attenuation or vibration "loss factor" include audio, optical, power generation, machining, sonar or vehicle systems. Higher attenuation typically improves a system's fatigue life. Specifically, material vibration decay is a subset of a comprehensive system's vibrational performance. Frequency, temperature, working environment, joints, interfaces, and distance from the source of energy within an assembly or system are examples that account for most cases of vibrational decay. The materials of construction play a role within the system's comprehensive vibration loss factor and are sometimes called internal friction.

Vibrational damping characteristics can be described using different interrelated parameters including viscous damping ratio (ζ), quality factor (Q), specific damping capacity (Ψ), and loss factor (η). Several Materion lightweight materials were tested to measure the loss factor (η) in 2016. A procedure using tuning forks was used to characterize vibration loss factor, under the recommendation of the testing laboratory.

Acoustic Properties of Beryllium Advantageous with Speaker Domes

Beryllium's low density reduces the mass and momentum of the diaphragm which reduces the energy required to drive and stop it. The same coil and magnet will react more quickly (faster transients and extended frequency response). The high stiffness minimizes distortion and bending waves. The exceptional damping characteristics mentioned earlier attenuate vibration faster than other available metals.

Other unique properties for acoustics include its velocity of sound, which is approximately twice that of other metals; an unusually low Poisson's ratio; and a high Debye temperature.

The velocity of longitudinal sound waves in beryllium is approximately 13,000 m/s. Other metals such as aluminum, magnesium and titanium, already present in ultrasonic applications, have velocities ranging between 5,800 and 6,400 m/s. Beryllium's low Poisson's ratio indicates reduced coupling of sound waves from one mode of propagation to another, limiting the possibility of signal confusion and reducing transverse and longitudinal motion at the node.

The Debye temperature is directly related to heat capacity, at least in the case of metallic materials. Simply put, the Debye temperature is the greatest temperature at which a material's crystal lattice remains "ordered". Generally, this temperature is greater for hard materials such as diamond and lower for softer materials like lead. The Debye temperature for beryllium is 1000K, much greater than the Debye temperature of other metals. As such, beryllium will experience less acoustic loss, especially at high frequencies, than other relevant metals.

CHART 9.2

Vibration Loss Factor for Lightweight Materials and Tempers

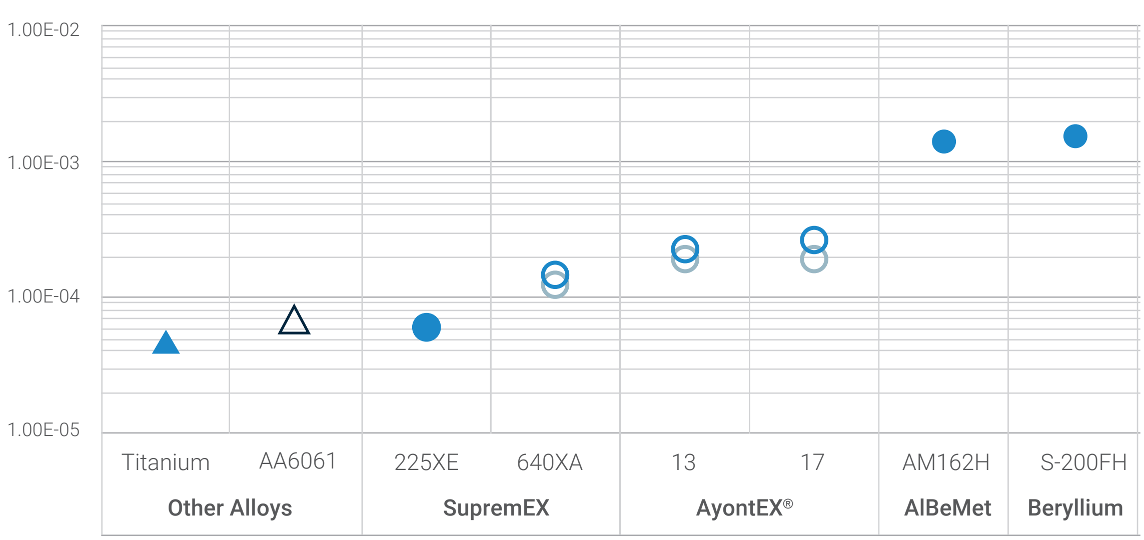


CHART 9.3

PROPERTY	Units	Acoustic Beryllium	Magnesium	Aluminum	Titanium
Density	g/cc	1.85	1.74	2.7	4.5
Young's Modulus	GPa	310	44	70	116
Longitudinal Sound Velocity	m/s	12,945	5,029	6,400	5,077
Poisson's Ratio		0.032	0.35	0.36	0.34
Debye Temperature	K	1000	370	398	380
Attenuation at <30 kHz	$Q^{-1} \times 10^4$	1-3	~5	1-5	~8

Nuclear and Physical Properties of Beryllium

Natural beryllium contains 100% of the Be^9 isotope. The principal isotopes of beryllium and their half-lives which have been identified are: Be^6, 0.4 seconds; Be^7, 53 days; Be^8, 10^{-16} seconds; Be^9, stable; Be^{10}, 2.5 X 10^6 yrs.

In nuclear applications, the main advantages of beryllium are very low Z value, high thermal conductivity, high resistance against thermal shock, no chemical reactions with hydrogen, and sputtering yields for energies below 50 eV, one order of magnitude smaller than for graphite at ambient temperature. Compared with graphite, the thermal shock resistance is nearly identical, but the thermal conductivity is a factor of 4 higher, decreasing the surface temperature in claddings of equal thickness. Hydrogen retention and chemical erosion are not expected to present problems as with graphite, and bonding techniques to the copper cooling structure are available. On the negative side, the permissible surface temperature will be lower for beryllium, hydrogen blistering may occur.

Atomic Number: 4

Atomic Weight: 9.0122

Crystal Structure:
Hexagonal Close-packed
a = 2.854,
c = 3.5829,
c/a = 1.5677

Body-Centered Cubic (above 1254°C):
a = 2.550

Density: 1.8477 g/cm³

Melting Point: 1287°C

Boiling Point: 2472°C

Vapor Pressure:
log P(atm) = 6.186 + 1.454 x 10^{-4} T-16 734 T^{-1}

Heat of Fusion:
2.8 kcal/mol

Heat of Sublimation:
76.56 kcal/mol

Heat of Evaporation:
53.55 kcal/mol

Specific Heat:
Cp = 4.54 + 2.12 x 10^{-3} T–0.82 x 105 T^{-2} cal/K/mol

Thermal Conductivity:
216 W/m K

Thermal Expansion:
11.5 x 10^{-6}/°C
(0-50°C)

Entropy 25°C:
2.28 cal/°C/mol

Enthalpy 25°C:
465 cal/mol

Electrical Resistivity:
4.31 µΩ cm

Magnetic Susceptibility (293 K):
−1.00 x 10^{-9} m³/kg

Velocity of Sound
12 600 m/s

Volume contraction on Solidification: 3%

X-Ray Transmittance

Information on the X-ray transmittance and attenuation can be found on the [National Institute of Standards and Technology (NIST) website.]

A useful calculator for estimating attenuation and transmittance values can be found on the NIST website. physics.nist.gov/PhysRefData/FFast/html/form.html. The graph shows the range of transmittance for beryllium and 1100 aluminum with a target of CuK alpha; energy 8.041keV; wavelength 1.5418 Angstroms.

Transmittance values per formula T= e -lρ∑ui fi where...

a. l = X-ray path length

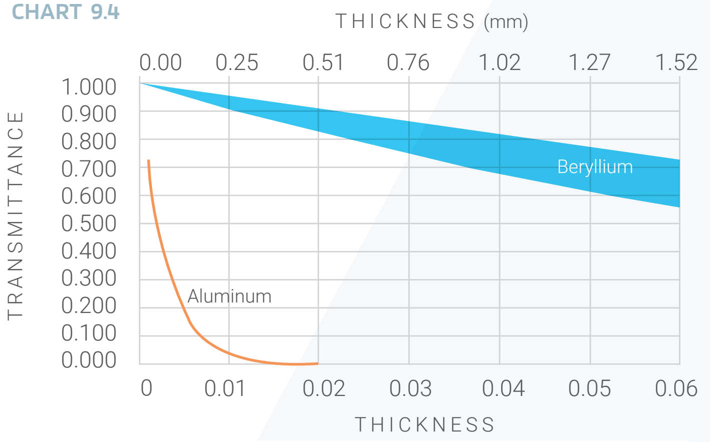
b. ρ = Mass density of material

c. fi = Fraction of material mass due to element (i)

d. ui = Mass absorption coefficient of element (i).

The three grades of beryllium foil (IF-5™, PF-60®, PS-200®) have varying grades of purity.

CHART 9.4



Beryllium Thickness vs. Transmittance

Environmental Health and Safety

Safe Handling of Beryllium-containing Materials

Handling beryllium and beryllium-containing materials 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) set mandatory limits on occupational respiratory beryllium exposures. Read and follow the guidance in the Safety Data Sheet (SDS) before working with this material. For additional information on the safe handling of beryllium, our Beryllium Worker Protection Model, and process-specific safety guidance, visit us online at www.materion.com, www.berylliumsafety.com or www.berylliumsafety.eu.

Environmental and Industry Regulations

Electronic products must conform to environmental regulations regarding the hazardous material content and end-of-life recyclability. The European RoHS (Restriction of Hazardous Substances) directive prohibits the use of lead (Pb), cadmium (Cd), mercury (Hg), hexavalent chromium (Cr^{6+}), and brominated flame retardants in most components. Beryllium-containing materials are not banned or restricted in any way by the European RoHS, Waste Electrical and Electronic Equipment (WEEE) or End-of-Life Vehicles (ELV) directives.

Additionally, the use of beryllium-containing materials is not banned, restricted, or otherwise limited by the IEC 62474 - Material Declaration for Products of and for the Electrotechnical Industry. IEC 62474 is a voluntary standard adopted by the International Electrotechnical Commission and supported by companies in the electronics industry.

Recycling Materion Materials

Information for recycling Materion materials can be found at https://www.materion.com/en/expertise/services/material-recycling--reclamation

Beryllium and beryllium-containing scrap that is not contaminated with other metals such as iron, aluminum, cadmium, lead etc. is readily recyclable by Materion. We purchase clean beryllium scrap for reprocessing into new beryllium-containing materials. Furthermore, beryllium containing materials are fully compliant with the RoHS directive. It is economically and environmentally advisable for the manufacturer or a recycler to segregate beryllium scrap from other metals for recycle.

Disposal of Beryllium and Beryllium-containing Materials

Beryllium does not pose a hazard to human health or the environment when discarded in a landfill and managed in accordance with existing federal and state requirements. As noted by the Agency for Toxic Substances and Disease Registry (ATSDR) in its 2023 report, beryllium in soils, like aluminum, is immobile because of its tendency to adsorb onto clay surfaces. Thus, beryllium has not been found to migrate or leach through soils to contaminate groundwater. Because beryllium is not a hazardous waste constituent and is not a listed hazardous waste under federal rules and regulations, wastes cannot be classified as hazardous due to the presence of beryllium.

Commercially pure beryllium powder or manufacturing intermediates in which beryllium powder is the sole active ingredient has been classified as hazardous waste under the Resource Conservation and Recovery Act (RCRA). Due to the limited scope of this definition, the only form of beryllium to which it applies is commercially pure metallic beryllium powder disposed of as a waste. Recycling is the preferred method of disposal and Materion is capable of recycling beryllium powder.

If you have any questions regarding the above information, please contact your sales representative, call the Materion Product Safety Hotline at 800.862.4118, or email us at Materion-PS@materion.com.

Materion Global Headquarters
6070 Parkland Boulevard
Mayfield Heights, OH 44124 USA
materion.com
connect@materion.com
+ 1 800.375.4205

MATERIAL GUIDE

MATERION