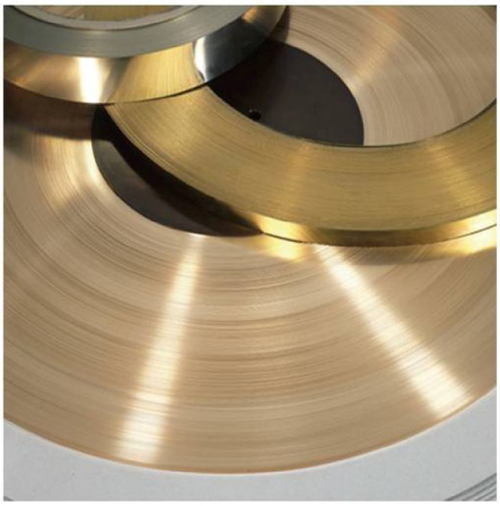
MATERION

Lamineries MATTHEY SA

Guide to High Performance Alloys



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LMSA_tech Doc 023
2014

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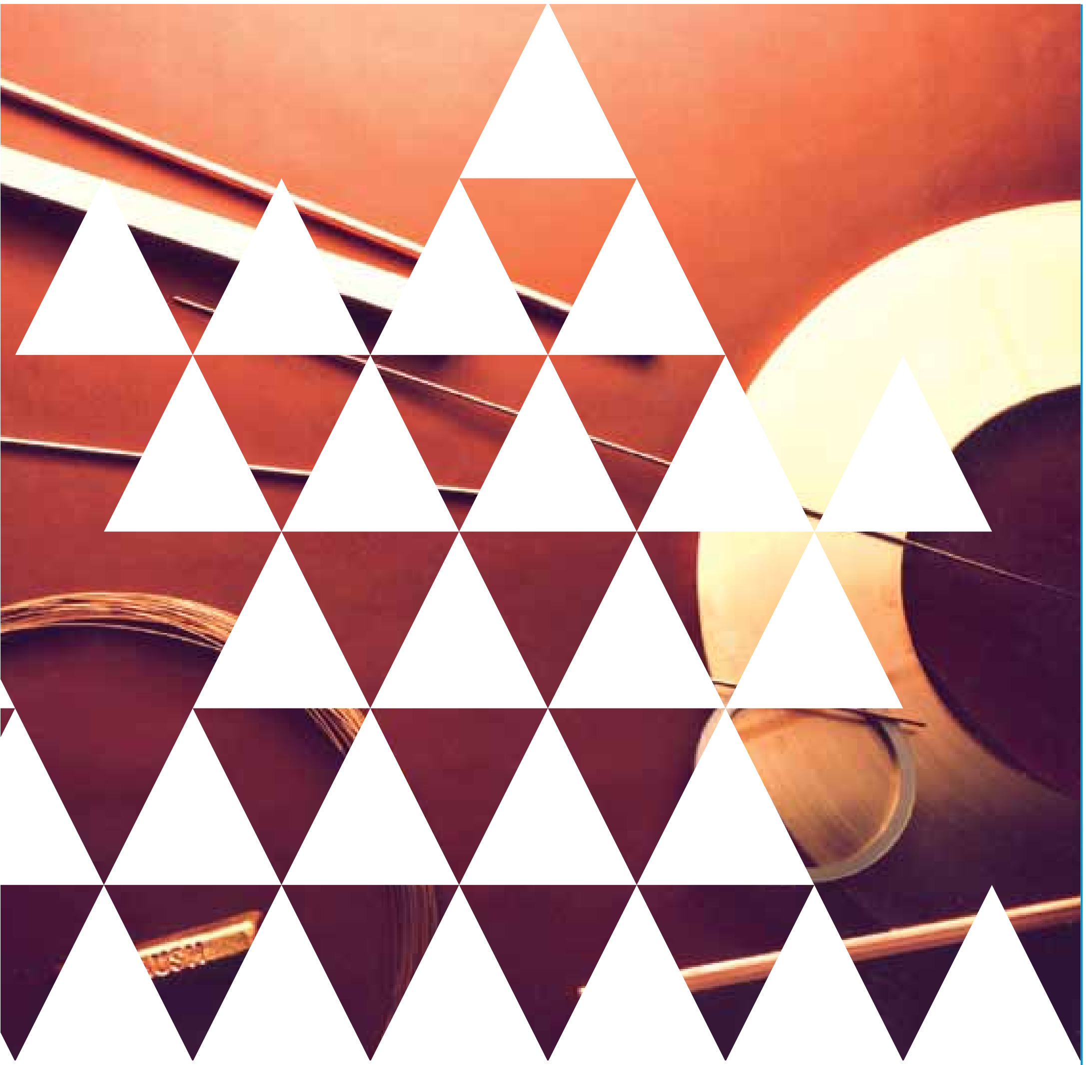

The copper and nickel alloys commonly supplied in wrought product form are highlighted in this section. Wrought products are those in which final shape is achieved by working rather than by casting. Cast alloys are described in a later section of this publication.

Although the alloys in this guide are foremost in the line that has established Materion Brush Performance Alloys' worldwide reputation for quality, they are not the only possibilities. We welcome the opportunity to work with you in selecting or developing an alloy to make your application succeed.

The Alloys of Materion Brush Performance Alloys

In addition to the standard alloys listed here, Materion Brush Performance Alloys has the capability to produce other copper alloys, or to provide toll processing of alloys cast elsewhere. Please consult with your local sales representative for further information.

Copper Beryllium

Materion Brush Performance Alloys manufactures copper beryllium in several distinct compositions. These fall into two categories: alloys selected for **high strength** (Alloys 25, 190, 290, M25 and 165) and alloys selected for **high conductivity** (Alloys 3, 10, 174 and Brush 60®). Alloy 390® combines both attributes, high strength and high conductivity. Many of these alloys are available in both heat treatable and mill hardened (pre-heat treated) conditions.

Alloy 25 is the most commonly specified copper beryllium and is available in the wrought forms listed on page 7. In its age hardened condition, Alloy 25 attains the highest strength and hardness of any commercial copper base alloy. The ultimate tensile strength can exceed 200 ksi, while the hardness approaches HRC 45. Also, in the fully aged condition, the electrical conductivity is a minimum of 22% IACS (International Annealed Copper Standard, where 100% IACS = 0.679 micro-ohm-inches or 1.72 micro-ohm-cm). Alloy 25 also exhibits exceptional resistance to stress relaxation at elevated temperatures.

Alloy 190 is a mill hardened strip product. The strip is age hardened to a specified strength level as part of the manufacturing process at Brush Performance Alloys prior to shipment. This alloy is similar to Alloy 25 in chemical composition. Alloy 190 is supplied with tensile strength up to 190 ksi. Cost effectiveness is realized by elimination of the need for age hardening and cleaning of stamped parts.

Alloy 290 is a mill hardened strip product that is similar in strength properties and composition to Alloy 190, but exhibits improved formability. Component reliability and fabrication considerations may require a high strength material with good formability. The improved strength/formability relationship of Alloy 290 makes it a cost effective alternative to conventional mill hardened product for such applications.

Alloy M25 offers the strength properties of Alloy 25 with the added benefit of being "free machining." Alloy M25 rod and wire contain a small amount of lead to provide an alloy tailored for automatic machining operations. Lead promotes formation of finely divided chips and extends cutting tool life.

Alloy 165 contains less beryllium than Alloy 25. and may be substituted when strength is less demanding. Alloy 165 is available in wrought product forms in heat treatable and aged tempers.

Alloys 3 and 10 combine moderate yield strength, up to 125 ksi, with electrical and thermal conductivity from 45 to 60 % of pure copper. Alloys 3 and 10 are available in wrought product forms and can be supplied fully hardened. Hardened products are identified by the temper designation AT or HT, and have good formability.

Brush 60® and Brush Alloy 174 offer users the opportunity to upgrade component performance over bronzes and brasses, particularly where conductivity and stress relaxation resistance are design considerations. They are supplied with yield strength up to 125 ksi, superior to other copper alloys such as phosphor bronze, silicon bronze, aluminum, brass and copper nickel alloys. Furthermore, they offer up to five-fold better electrical conductivity than those alloys, and exhibit better stress relaxation resistance. These alloys offer an excellent combination of elastic modulus, strength, formability and conductivity. Both are available as mill hardened strip.

Alloy 390® and Alloy 390E® combine the best attributes of the two separate families of commercial copper beryllium alloys – the strength of the "high strength" Alloy 25 with the conductivity of "high conductivity" Alloys 3 and 174. In addition to the combination of high strength and conductivity, Alloys 390® and 390E® have excellent stress relaxation resistance at elevated temperatures. In applications where durability is important, their excellent fatigue strength extends product life and improves product quality. Alloy 390® and 390E® are available as prehardened strip.

Alloy 310 is a copper nickel cobalt beryllium alloy with high electrical and thermal conductivity. It possesses good strength and hardness, and has been shown to have excellent thermal fatigue resistance. It is typically used in welding electrodes as well as dies, plunger tips and nozzles for metal die casting.

Nickel Beryllium

Alloy 360 nickel beryllium strip features high strength and stiffness usually associated with steel and nickel alloys, while retaining excellent formability. It can withstand temperatures up to 700° F (375 °C) without losing spring properties, and will retain over 90% of its initial stress over 1,000 hours at that temperature.

ToughMet®

Materion Brush Performance Alloys produces a number of engineered high performance copper alloys using a patented technology called EquaCast®. The process produces an extremely uniform, fine-grained microstructure and promotes excellent dispersion of alloy elements for high quality, consistent products.

ToughMet® 2 is a spinodally hardened copper nickel tin alloy possessing outstanding lubricity and machinability. Its corrosion resistance is superior to most other copper alloys, with hardness up to HRC 27. It is used for wear plates and low friction bushings and bearings.

ToughMet® 3 is a spinodally hardened copper nickel tin alloy, possessing much higher strength and hardness, equivalent to Alloy 25. It has exceptional tarnish resistance at room temperature, and its corrosion resistance is even greater than that of Alloy 25 or ToughMet® 2. It is used for heavily loaded bushings or bearings commonly found in aircraft, off-road equipment and industrial machinery. It is often used for sour oilfield service, and is compliant to NACE MR0175/ISO 15156 with no restriction on hardness.

Other Alloys

BrushForm® 158 is a spinodally hardened copper nickel tin strip alloy available in age hardenable or mill hardened form. The age hardenable variety features strength, formability, and stress relaxation resistance similar to Alloy 25, while the properties of the mill hardened grade are similar to BrushForm® 290. It has lower conductivity than the equivalent copper beryllium alloys, but does not contain beryllium. It does not contract when hardened, so it is less prone to distortion during heat treatment than Alloy 25.

BrushForm® 96 is a spinodally hardened copper nickel tin strip alloy available in age hardenable or mill hardened form. It has higher conductivity than the BrushForm® 158 at slightly lower strength levels.

C95510 is a fine-grained aluminum nickel bronze alloy with high strength, ductility and good abrasion resistance. It is typically used for aerospace bushings and bearings.

Brush 1915® and Brush 1916 are leaded copper nickel rod and wire alloys. Both possess good machinability and strength, and are engineered for use in automatic screw machining processes. Brush 1915® has lower lead for improved cold head ability.

FormaMet® is a machinable die bronze used for deep drawing or forming of stainless and low carbon steels. It combines high hardness (typically 39 HRC) with excellent lubricity and high resistance to wear and galling. It promotes extended tool life and minimizes wrinkling and tearing of drawn parts.

Plastic Tooling Alloys

Materion Brush Performance Alloys also manufactures MoldMAX® and PROtherm™ alloys for use as tooling and inserts in the plastic molding industries.

MoldMAX HH® is a high strength copper beryllium alloy, with typical hardness of HRC 40 and thermal conductivity of 75 BTU/ft·hr·°F (130 W/m·°C). Its hardness and wear resistance make it suitable for injection mold components and long life in wear-prone blow mold components.

MoldMAX LH® is heat treated to an optimum toughness at a hardness of HRC 30. It has higher thermal conductivity of 90 BTU/ft·hr·°F (155 W/m·°C) and greater impact strength. It is used in place of the HH temper where faster cycles and improved toughness are needed.

PROtherm™ (formerly MoldMAX SC®) is a high conductivity copper beryllium alloy, with hardness around HRC 20 and a thermal conductivity of 145 BTU/ft·hr·°F (250 W/m·°C). It is typically used for blow mold inserts or hot runner nozzle tips.

MoldMAX XL® is a copper nickel tin spinodally hardened alloy with a hardness of HRC 30 and a thermal conductivity of 40 BTU/ft·hr·°F (70 W/m·°C). It is typically used for injection mold components requiring good polishability and large sizes.

MoldMAX V® is a copper nickel silicon chromium alloy with hardness of HRC 28 and thermal conductivity of 92 BTU/ft·hr·°F (160 W/m·°C). It is typically used for fast cycle injection mold components.

Alloy C18000 is a copper nickel silicon chromium alloy, with hardness of HRC 16 and conductivity of 135 BTU/ft·hr·°F (235 W/m·°C). It is typically used for faster cycle mold components. It is a lower cost alternative to the MoldMAX® family of alloys.

Bar is a solid rectangular or square section thicker than 3/16 inch (0.48 mm) and up to and including 12 inches (30 mm) wide. Bar is typically an extruded product. If cut from plate it is called rolled bar. Edges are either sharp, rounded, or have some other simple shape.

Plate is flat-rolled product thicker than 0.188 inch (4.78 mm) and over 12 inches (30.48 mm) wide.

Forgings are supplied in forms ranging from simple geometric configurations to near net shapes according to user specifications. Some examples are large size ToughMet® rings or MoldMAX® plate.

Extruded shape is a solid section other than round, hexagonal, octagonal or rectangular. Shapes are produced to the user's specification and are supplied in straight lengths.

Cast shapes are continuous cast shapes with solid or hollow cross sections other than round. The use of these near-net shapes reduces part input weight and machining time, reducing manufacturing cost.

Custom fabricated parts can be made to specification from drawings supplied by the customer. Such products are fabricated from basic product forms (rod, extrusions, plate, etc.) by processes such as ring rolling, forging, welding and machining.

Physical Properties

Copper beryllium's physical and mechanical properties differ considerably from those of other copper alloys because of the nature and action of the alloying elements, principally beryllium. Varying the beryllium content from about 0.15 to 2.0 weight % produces a variety of alloys with differing physical properties. Typical values of some of these properties are presented in the table on the next page.

Some properties remain similar across all copper alloys. For example, the elastic modulus ranges from a low of 16 million psi (110 GPa) for C95510 and FormaMet® to a high of 21 million psi (138 GPa) for the ToughMet® alloys. Alloy 360 nickel beryllium alloy is nickel-based, not copper-based, so it has a much higher elastic modulus value, ranging from 28 to 30 million psi (193 to 207 GPa). Prior to age hardening, the elastic modulus of the heat treatable alloys may be 1 to 2 million psi (7 to 14 GPa) lower.

A physical property that differs significantly among alloy families is thermal conductivity, driven in part by alloy additions. In copper beryllium, it ranges from about 60 BTU/ft ·hr ·°F (105 W/m ·K) for high strength alloys to 140 BTU/ft ·hr ·°F (240 W/m ·K) for the high conductivity alloys, as well as for the Brush 1915®, and the C18000. MoldMAX V® has a conductivity intermediate to these ranges, while MoldMAX XL® is slightly lower. The thermal and electrical conductivities of these alloys promotes their use in applications requiring heat dissipation and current carrying capacity. The other alloys show lower thermal conductivities. The conductivities of the bulk (rod, bar, plate, and tube) alloys will be about 10% greater than that of the strip alloys.

Electrical conductivity is listed with mechanical properties in the Product Guide section of this book. It is typically specified in % IACS (International Annealed Copper Standard). A material with 100% IACS conductivity has an electrical resistivity of 6.79 micro-ohm inches (1.72 micro-ohm cm). The conductivity of a given material is expressed as a ratio of this theoretically maximum value. (Note: modern deoxidized high copper alloys can have a conductivity as great as 102% IACS. Achieving conductivity greater than the specification minimum may require reduced mechanical properties.)

The specific heats of copper alloys rise with temperature. For Alloys 25, M25 and 165, it is 0.086 BTU/lb ·°F (360 J/kg ·K) at room temperature, and 0.097 BTU/lb ·°F (406 J/kg.K) at 200°F (93°C). For Alloys 3, 10, 174, Brush 60® and 390, it rises from 0.080 to 0.091 BTU/lb ·°F (335 to 381 J/kg ·K) over the same temperature range. ToughMet® 2 increases from 0.090 to 0.093 BTU/lb ·°F (377 to 389 J/kg ·K), and ToughMet® 3 from 0.090 to 0.100 BTU/lb ·°F (377 to 419 J/kg ·K).

Magnetic permeability in the copper beryllium and in the ToughMet® alloys is very close to unity, meaning that the alloys are nearly perfectly transparent to slowly varying magnetic fields.

Poisson's ratio ranges from 0.30 to 0.33 for all compositions and product forms.

Copper beryllium high strength alloys are less dense than conventional specialty coppers, often providing more pieces per pound of input material. Copper beryllium also has an elastic modulus 10 to 20% higher than other specialty copper alloys. Strength, resilience and elastic properties make copper beryllium the alloy of choice, while the other high performance alloys come close.

Chemical Com

Alloy Composition (Weight Percent)

	Brush Alloy	UNS Number	ISO/EN Designation	Beryllium (Be)	Nickel (Ni)	Cobalt (Co)	Iron (Fe)	Cobalt (Co) + Nickel (Ni)	Cobalt (Co) + Nickel (Ni) + Iron (Fe)	Tin (Sn)	Lead (Pb)	Zinc (Zn)	Aluminum (Al)	Silicon (Si)	Chromium (Cr)	Manganese (Mn)	Phosphorous (P)	Titanium (Ti)
High Strength Copper Beryllium	25 190 290	C17200	CuBe2	1.80-2.00	-	-	-	0.20 min.	0.6 max.	-	0.02 max.	-	-	-	-	-	-	-
	M25	C17300	CuBe2Pb	1.80-2.00	-	-	-	0.20 min.	0.6 max.	-	0.20-0.6	-	-	-	-	-	-	-
	165	C17000	CuBe1,7	1.60-1.85	-	-	-	0.20 min.	0.6 max.	-	0.02 max.	-	-	-	-	-	-	-
High Conductivity Copper Beryllium	3	C17510	CuNi2Be	0.2-0.6	1.4-2.2	-	-	-	-	-	-	-	-	-	-	-	-	-
	310	-	CuCoNiBe	0.4-0.7	0.8-1.3	0.8-1.3	-	-	-	-	-	-	-	-	-	-	-	-
	10	C17500	CuCo2Be	0.4-0.7	-	2.4-2.7	-	-	-	-	-	-	-	-	-	-	-	-
	174	C17410	CuCo0,5Be0,3	0.15-0.50	-	0.35-0.6	-	-	-	-	-	-	-	-	-	-	-	-
	Brush 60® Alloy 390®	C17460	-	0.15-0.50	1.0-1.4	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel Beryllium	360	N03360	NiBe2	1.85-2.05	Balance	-	-	-	-	-	-	-	-	-	-	-	-	0.4.-0.6
ToughMet®	ToughMet® 2 BrushForm® 96	C96970 C72700	CuNi9Sn6	-	8.5-9.5	-	0.5 max.	-	-	5.5-6.5	-	0.5 max.	-	-	-	-	-	-
	ToughMet® 3 BrushForm® 158	C96970 C72900	CuNi15Sn8	-	14.5-15.5	-	0.5 max.	-	-	7.5-8.5	-	0.5 max.	-	-	-	-	-	-
Other Alloys	C95510	C95510	-	-	4.5-5.5	-	3.0-7.0	-	-	0.2 max.	-	0.3 max.	9.7-10.9	-	-	1.5 max.	1.5 max	-
	Brush 1915®	C19150	CuNiPb1P	-	0.8-1.2	-	-	-	-	-	0.5-1.0	-	-	-	-	-	0.15-0.35	-
	Brush 1916	C19160	CuNiPb1P	-	0.8-1.2	-	-	-	-	-	0.8-1.2	0.5 max	-	-	-	-	0.15-0.35	-
	FormaMet®	Propiertary Composition Die Bronze																
Plastic Mold Tooling Alloys	MoldMAX HH® MoldMAX LH®	-	-	1.80-2.00	-	-	-	0.20 min.	0.6 max.	-	0.02 max.	-	-	-	-	-	-	-
	PROtherm™	-	-	0.2-0.6	1.4-2.2	-	-	-	-	-	-	-	-	-	-	-	-	-
	MoldMax XL®	-	-	-	8.5-9.5	-	0.5 max.	-	-	5.5-6.5	-	0.5 max.	-	-	-	-	-	-
	MoldMax V®	-	-	-	6.5-7.5	-	-	-	-	-	-	-	-	1.5-2.0	0.75-1.25	-	-	-
	C18000	C18000	CuNi2Si	-	1.8-3.0	-	-	-	-	-	-	-	-	0.4-0.8	0.1-0.8	-	-	-

Alloy Products

Wrought copper beryllium, ToughMet® and other high performance alloys are available from Materion Brush Performance Alloys in a variety of product forms. The following paragraphs define the products most commonly specified by the users of these alloys.

Strip is flat-rolled product, other than flat wire, 0.188 inch (4.78 mm) or less in thickness. Thinner gauges under 0.090 (2.29 mm) inch are supplied in coil form, while thicker gauges also may be supplied in sheet form.

Wire is a solid section other than strip, furnished in coils or on spools or reels. Wire may be furnished straightened and cut to length, in which case it is classified as rod.

Flat wire is 0.188 inch (4.78 mm) or less in thickness and 1-1/4 inch (31.75 mm) or less in width. This designation includes square wire 0.188 inch (4.78 mm) or less in thickness. In all cases surfaces are rolled or drawn without having been slit, sheared or sawed. Flat wire is furnished in straight lengths or on spools or reels.

Rod is a round, solid section furnished in straight lengths. Rod is supplied in random or specific lengths.

Tube is typically a seamless hollow product with round or other cross section. Tube is normally extruded or drawn, and is supplied in random or specific lengths.

Standard Product Forms

	Materion Brush Performance Alloys Designation														
Form	**25, 3**	**165**	**10**	**M25**	**Alloy 290, 190, 174 Alloy 390®, 390E®, 360, Brush 60®, BrushForm® 158, BrushForm® 96**	**Brush 1915®, Brush 1916**	**310**	**ToughMet® 3 CX Tempers**	**ToughMet® 3 AT Tempers**	**ToughMet® 3 TS Tempers**	**ToughMet® 2**	**C95510**	**FormaMet®**	**C18000**	**MoldMAX® HH, LH, XL, V and PROtherm™**
Cold Rolled															
Strip	✓	-	-	-	✓	-	-	-	-	-	-	-	-	-	-
Flat Wire	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rectangular Bar	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Square Bar	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plate	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cold Drawn															
Rod	✓	✓	-	✓	-	✓	✓	-	-	✓	-	-	-	-	-
Bar	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-
Tube	✓	-	-	-	-	-	-	-	-	✓	-	-	-	-	-
Wire	✓	-	-	✓	-	✓	-	-	-	✓	-	-	-	-	-
Shapes	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Worked															
Rod	✓	✓	✓	-	-	-	✓	-	✓	-	-	-	✓	✓	✓
Bar	✓	✓	✓	-	-	-	✓	-	-	-	-	-	-	✓	✓
Plate	✓	✓	-	-	-	-	✓	-	✓	-	✓	-	✓	✓	✓
Tube	✓	✓	✓	-	-	-	-	-	✓	-	-	-	-	✓	✓
Cast Shapes															
Rod	-	-	-	-	-	-	-	✓	-	-	✓	-	-	-	-
Tube	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	-
Custom X-Section	-	-	-	-	-	-	-	✓	-	-	✓	-	-	-	-
Special Shapes															
Turned Rod	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-
Billets	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-
Forgings	✓	✓	-	-	-	-	✓	-	✓	-	-	-	✓	✓	✓
Extrusions	✓	✓	-	-	-	-	-	-	✓	-	-	-	-	-	-
Machined Parts	✓	✓	-	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	-

Typical Physical Properties

	Density[1]	Elastic Modulus	Thermal Expansion Coefficient	Thermal Conductivity		Melting Range[2]	Specific Heat Capacity	
				70°F / 20°C	200°F / 100°C		70°F / 20°C	200°F / 100°C
Brush Alloy	lb/in^3	10^6 psi	in/in/°F, 70 °F to 400 °F	BTU/ft hr °F	BTU/ft hr °F	°F	BTU/lb °F	BTU/lb °F
	g/cm^3	GPa	m/m/C, 20 °C to 200 °C	W/m K	W/m K	°C	J/kg K	J/kg K
25, 190, 290	0.302	19	9.7×10^6	60	75	1600 - 1800	0.086	0.097
	8.36	131	17.5×10^6	105	130	870 - 980	360	406
M25	0.302	19	9.7×10^6	60	75	1600 - 1800	0.086	0.097
	8.36	131	17.5×10^6	105	130	870 - 980	360	406
165	0.304	19	9.7×10^6	60	75	1600 - 1800	0.086	0.097
	8.41	131	17.5×10^6	105	130	870 - 980	360	406
3	0.319	20	9.8×10^6	140	-	1900 - 1980	0.08	0.091
	8.83	138	17.6×10^6	240	-	1040 - 1080	335	381
10	0.319	20	9.8×10^6	115	-	1850 - 1930	0.08	0.091
	8.83	138	17.6×10^6	200	-	1010 - 1050	335	381
310	0.318	20	9.8×10^6	135	-	1880 - 1975	0.08	0.091
	8.80	135	17.6×10^6	235	-	1030 - 1080	335	381
Brush 60®	0.318	20	9.8×10^6	128	-	1880 - 1960	0.08	0.091
	8.80	138	17.6×10^6	225	-	1030 - 1070	335	381
174	0.318	20	9.8×10^6	135	-	1880 - 1960	0.08	0.091
	8.80	138	17.6×10^6	235	-	1030 - 1070	335	381
Alloy 390®	0.318	20	9.8×10^6	128	-	1880 - 1960	0.08	0.091
	8.80	138	17.6×10^6	222	-	1030 - 1070	335	381
Alloy 390E®	0.319	20	9.8×10^6	120	-	1850 - 1930	0.1	-
	8.83	138	17.6×10^6	208	-	1010 - 1050	419	-
360	0.299	28 - 30	8.0×10^6	28	-	2185 - 2420	0.11	-
	8.28	193 - 207	14.4×10^6	48	-	1200 - 1330	461	-
BrushForm® 158	0.325	20	9.1×10^6	22	27	1740 - 2040	0.09	0.10
	9.00	144	16.4×10^6	38	47	950 - 1115	377	419
BrushForm® 96	0.322	20	9.0×10^6	30	-	1695 -	0.09	0.093
	8.91	140	16.2×10^6	52	-	925 -	377	389
ToughMet® 3	0.325	21	9.1×10^6	22	27	1740 - 2040	0.09	0.10
	9.00	144	16.4×10^6	38	47	950 - 1115	377	419
ToughMet® 2	0.322	17	9.0×10^6	30	-	1695 -	0.09	0.093
	8.91	117	16.2×10^6	52	-	925 -	377	389
Brush 1915®, 1916	0.320	18	9.8×10^6	120	-	1980 -	0.092	-
	8.86	124	17.6×10^6	210	-	1080 -	385	-
C95510	0.272	16	9.0×10^6	24	-	1900 - 1930	0.09	-
	7.53	110	16.2×10^6	42	-	1040 - 1050	375	-
FormaMet®	0.251	16	9.0×10^6	19	-	1980 -	0.1	-
	6.94	110	16.2×10^6	33	-	1080 -	420	-
MoldMAX HH®	0.302	19	9.7×10^6	-	75	1600 - 1800	0.086	0.097
	8.36	131	17.5×10^6	-	130	870 - 980	360	406
MoldMAX LH®	0.302	19	9.7×10^6	-	90	1600 - 1800	0.086	0.097
	8.36	131	17.5×10^6	-	155	870 - 980	360	406
PROtherm™	0.319	20	9.8×10^6	-	145	1900 - 1980	0.08	0.091
	8.83	138	17.6×10^6	-	250	1040 - 1080	335	381
MoldMAX XL®	0.322	17	9.0×10^6	-	40	1695 -	0.09	0.093
	8.91	117	16.2×10^6	-	70	925 -	377	389
MoldMAX V®	0.314	18	9.7×10^6	-	92	1800 -	-	0.098
	8.69	124	17.5×10^6	-	160	980 -	-	410
C18000	0.320	18	9.7×10^6	-	120	1900 -	0.092	-
	8.86	124	17.5×10^6	-	208	1040 -	385	-

NOTE: 1) Tabulated properties apply to age hardened products. Before age hardening the density is: 0.300 lbs/in^3 for Alloys 25 and M25; 0.302 lbs/in^3 for Alloy 165; 0.316 lbs/in^3 for Alloys 3 and 10. 2) Melting Range is expressed as solidus - liquidus.

Product Guide

Materion Brush Performance Alloys' products are recognized worldwide for unequalled quality and reliability among high performance copper base alloys. The products are stocked in a wide range of sizes and shapes. Moreover, because these alloys perform well in most metal working and joining processes, special configurations can be produced economically.

Mechanical and electrical properties are presented in this section. These properties aid design by guiding size and temper selection, but the tabulations do not limit our selection. A narrower range or a property outside the range are frequently requested. We often produce to user specifications and we welcome the challenge of a special product.

Strip and Wire Temper Designations

Copper beryllium, Alloy 360 nickel beryllium, and copper nickel tin properties are determined in part by composition, but cold work and age hardening are also important. The combined effect of non-compositional factors is defined in the alloy's "temper." When alloy number and temper are specified on a drawing or order, for example Brush Alloy 3 AT, the user is assured of a specific set of properties.

Temper designations are defined in the specification ASTM B 601, "Standard Practice for Temper Designations for Copper and Copper Alloys." Less precise terms such as "quarter hard" and "half hard" are also recognized by suppliers and users. The relationship between these terms and the ASTM nomenclature is given in the table on this page.

Copper beryllium, nickel beryllium and copper nickel tin strip in the solution annealed condition is designated by a suffix letter "A". (Alloy 25 A for example.) This is the softest condition in which the alloy can be obtained. The suffix letter "H" denotes an alloy that has been fully hardened by cold working, such as by rolling or drawing, for example Alloy 25 H. The suffix letter "T" following an "A" or "H" designates an alloy which has been given a standard heat treatment, and as a result has "peak" properties, for example Alloy 25 HT.

Copper beryllium bearing an "M" suffix has received proprietary mill processing, for example Alloy 190 HM, and guarantees properties within a specific range. Alloy 3 is available in the fully aged condition. The products are designated AT for annealed and precipitation treated; and HT for annealed, cold rolled and precipitation treated. Brush 60® and Alloy 174 are provided only in the cold rolled, precipitation treated condition.

The Alloy 360 tempers that have been given proprietary mill hardening treatments are designated with the prefix "MH." Alloy 290 copper beryllium and BrushForm® 158 copper nickel tin mill hardened tempers begin with the prefix "TM."

Customized tempers are also available. These are typically designated with an "S" at the end of the standard temper name, such as HTS.

Standard Product Forms

Brush Designation	ASTM Designation	Description
A	TB00	Solution Annealed
1/4 H	TD01	Solution Annealed, then Cold Rolled or Cold Drawn to Quarter Hard
1/2 H	TD02	Solution Annealed, then Cold Rolled or Cold Drawn to Half Hard
3/4 H	TD03	Solution Annealed, then Cold Rolled or Cold Drawn to Three-Quarter Hard
H	TD04	Solution Annealed, then Cold Rolled or Cold Drawn to Full Hard
EH	TD08	Solution Annealed, then Cold Rolled or Cold Drawn to ExtraHard
AT 1/4 HT 1/2 HT 3/4 HT HT EHT	TF00, TX00 TH01, TS01 TH02, TS02 TH03, TS03 TH04, TS04 TS08	The suffix "T" added to temper designations indicates that the material has been age hardened by the standard heat treatment. The TF and TH tempers are used for precipitation age hardened materials like copper beryllium and nickel beryllium, and the TX and TS tempers are used for spinodally hardened alloys like BrushForm® 158.
AM 1/4 HM 1/2 HM HM SHM XHM XHMS -	TM00 TM01 TM02 TM04 TM05 TM06 TM08 TM10	Mill hardened to specific property ranges, no further heat treatment is required. Strip products only.
MH2 MH4 MH6 MH8 MH10 MH12	- - - - - -	Mill hardened to provide properties not available by standard age hardening. Alloy 360 nickel beryllium strip only.

Strip

Materion Brush Performance Alloys high performance alloy strip is used across a broad spectrum of applications. For example, a formed spring is often the active element in a signal or current directing device. In a connector, a copper alloy contact regulates insertion force to encourage contact wiping action, provides a high normal force to minimize contact resistance, and maintains withdrawal force to ensure conducting path integrity.

This accomplishment often requires an intricate stamped contact that combines flexing and stiffening members in the same part. Among the many tempers described on this and the following pages, there is one with compliance and formability to meet requirements of nearly any contact spring design.

Other benefits of copper beryllium and spinodally hardened copper nickel tin strip include the following:

- In many tempers, strength and forming characteristics do not vary with direction (isotropic). Deep drawn bellows or disc diaphragms for pneumatic controls depend on nondirectional properties both in manufacture and in service. Please inform Brush Performance Alloys if you intend to deep draw, so that we may provide the proper dead soft temper.
- Shielding strips that ground electromagnetic interference have demanding forming requirements, but also require strength and endurance.
- Relay contacts and switch parts must resist the action of repeatedly applied loads, sometimes at moderately elevated temperature, and therefore must have high fatigue strength.
- High hardness is a benefit in insulation displacement connectors that must cut through conductor wire insulation to make reliable contact.

Alloy 360 nickel beryllium strip has exceptional thermal stability and stress relaxation resistance. Since it is a nickel alloy, it also has outstanding corrosion resistance. Its formability is significantly better than stainless steels of similar strengths. These characteristics make it ideal for use in Belleville washers in fire protection sprinkler heads or in high temperature thermal controllers.

Thickness is critical in spring design, strongly influencing force-deflection characteristics. For this reason Brush Performance Alloys guarantees strip thickness to be uniform within tolerance limits shown in the adjoining table. Width of the slit strip is held to ±0.003 inch (± 0.076mm) in all widths up to 3.5 inches (± 89mm).

Strip curvature, either edgewise (camber), or out of the plane of the strip (coilset or crossbow) also is carefully controlled. In press working, excellent strip shape aids proper feed and increases speed, particularly with progressive dies. Please note that shape control becomes increasingly difficult at very thin gauges.

Materion Brush Performance Alloys also offers several additional manufacturing services for strip alloys. These include traverse winding, welded and marked coils, tension leveling of cold rolled strip, shearing and cutting to length, tin and solder coatings, inlay or overlay cladding, plating, multigauge contouring, electron beam welding and zone annealing. Please contact a Brush Performance Alloys representative for more information.

Strip Tolerance

(inches)

Strip Thickness		Brush Standard Tolerance
Over	Including	(plus or minus)
	0.0020	0.00010
0.0020	0.0040	0.00015
0.0040	0.0060	0.00020
0.0060	0.0090	0.00025
0.0090	0.0130	0.00030
0.0130	0.0260	0.00040
0.0260	0.0370	0.00060
0.0370	0.0500	0.00080
0.0500	0.0750	0.00100

(mm)

Strip Thickness		Brush Standard Tolerance
Over	Including	(plus or minus)
	0.05	0.003
0.05	0.10	0.004
0.10	0.20	0.006
0.20	0.30	0.008
0.30	0.70	0.010
0.70	1.0	0.016
1.0	1.3	0.020
1.3	2.0	0.025

NOTE: Tolerances apply to rolled and mill hardened strip. Additional tolerances are per ASTM B248. Please specify your required tolerance when you order. Tighter tolerances may be available at additional cost. Please contact your sales engineer to confirm the requested capability.

Strip Product Specifications

The table below is a listing of the specifications to which Materion Brush Performance Alloys' strip alloys are most commonly produced. Material is typically produced to the relevant ASTM standard, unless it is otherwise specified at the time it is ordered. Many of the specifications have unique requirements, so it is generally not possible to change the certification to a different specification without running the appropriate laboratory tests.

The old Federal (QQ) specifications are non-current, and have been superseded by the ASTM specification for each respective alloy. Similarly, the BS, DIN, NF, ISO, UNE and UNI specifications have been superseded by the new European EN specifications.

Only "current" specifications should be used for ordering purposes. "Withdrawn" specs are listed below for reference only, as they may appear on older drawings.

Strip Specifications[1]

Brush Alloy	UNS Number	Current	Withdrawn/Superseded[2]
25	C17200	ASTM B 194, B 888 AMS 4530, 4532 SAE J 461,463 EN 1652, 1654,14436 JIS H 3130	QQ-C-533 DIN 17666, 17670, 1777 NF A 51-109 ISO 1187, 1634 UNE 37-103, 37-105 UNI 2528 BS 2870, 2875 MIL-C-6942
190	C17200	ASTM B 194, B 888 EN 1652, 1654,14436 JIS H 3130	BS 2870, 2875 DIN 17666, 17670, 1777
290	C17200	ASTM B 194	-
3	C17510	ASTM B 534, B 888 EN 1652, 1654, 14436 MIL-C-81021	BS 2870, 2875 DIN 17666, 17670, 1777 ISO 1187, 1634
174	C17410	ASTM B 768, B 888	-
Brush 60®	C17460	ASTM B 768, B 888	-
Alloy 390®	C17460	-	-
BrushForm® 158	C72900	ASTM B 740	-
360	N03360	-	MIL-B-63573

ASTM	American Society for Testing and Materials
SAE	Society of Automotive Engineers
AMS	Aerospace Materials Specification (published by SAE)
EN	Comité Européen de Normalisation (Europe)
JIS	Japanese Industrial Standard (Japan)
QQ	US Federal Specification
MIL	US Military Specification
ISO	International Standards Organization
DIN	Deutsches Institut fur Normung (Germany)
BS	British Standard (UK)
NF	Association Française de Normalisation (France)
UNE	Instituto Español de Normalización (Spain)
UNI	Ente Nazionale Italiano di Unificazione (Italy)

NOTE: 1) Unless otherwise specified, material will be produced to ASTM specifications. 2) Withdrawn and superseded specifications are listed for reference only, and are not to be used for purchasing. Please contact Materion Brush Performance Alloys to determine the appropriate replacement specification.

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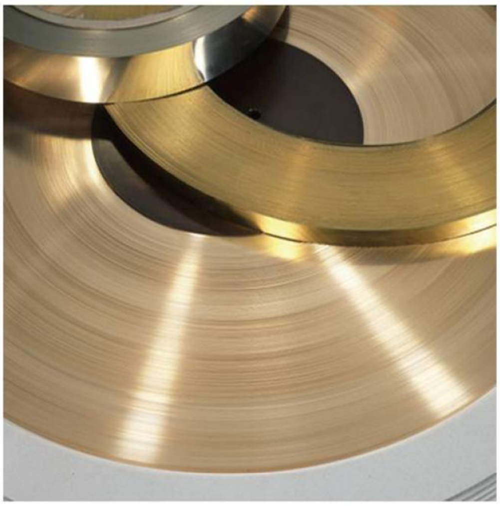
Guide to Copper Beryllium



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LMSA_tech Doc 023
2014

Mechanical and Electrical Properties of Copper Beryllium Strip

Alloy	Temper[1]	Available Sizes	Tensile Strength	Yield Strength 0.2% Offset	Elongation[3]	Fatigue Strength 10^8 cycles, R=-1	Hardness[4]			Electrical Conductivity
		in / mm	ksi / MPa	ksi / MPa	%	ksi / MPa	DPH or Vickers	Rockwell	Superficial Rockwell	(%IACS)
25 C17200	A Dead Soft (TB00)[2]	.00197 - .15 / .05 - 3.81	60 - 76 / 410 - 530	28 - 36 / 190 - 250	35 - 75	30 - 35 / 210 - 240	90 - 144	B45 - 78	30T 46 - 67	15 - 19
	A Planished (TB00)[2]	.00197 - .15 / .05 - 3.81	60 - 78 / 410 - 540	30 - 55 / 200 - 380	35 - 75	30 - 35 / 210 - 240	90 - 144	B45 - 78	30T 46 - 67	15 - 19
	1/4 H (TD01)	.00175 - .15 / .045 - 3.81	75 - 88 / 510 - 610	60 - 80 / 410 - 560	20 - 45	31 - 36 / 210 - 250	121 - 185	B68 - 90	30T 62 - 75	15 - 19
	1/2 H (TD02)	.0015 - .15 / .038 - 3.81	85 - 100 / 580 - 690	75 - 95 / 510 - 660	12 - 30	32 - 38 / 220 - 260	176 - 216	B88 - 96	30T 74 - 79	15 - 19
	H (TD04)	.0012 - .15 / .0305 - 3.81	100 - 120 / 680 - 830	90 - 115 / 620 - 800	2 - 18	35 - 39 / 240 - 270	216 - 287	B96 - 102	30T 79 - 83	15 - 19
	AT (TF00)[5]	- / -	165 - 195 / 1130 - 1350	140 - 175 / 960 - 1210	3 - 15	40 - 45 / 280 - 310	353 - 413	C36 - 42	30N 56 - 62	22 - 28
	1/4 HT (TH01)[6]	- / -	175 - 205 / 1200 - 1420	150 - 185 / 1030 - 1280	3 - 10	40 - 45 / 280 - 310	353 - 424	C36 - 43	30N 56 - 63	22 - 28
	1/2 HT (TH02)[6]	- / -	185 - 215 / 1270 - 1490	160 - 195 / 1100 - 1350	1 - 8	42 - 47 / 290 - 320	373 - 435	C38 - 44	30N 58 - 63	22 - 28
	HT (TH04)[6]	- / -	190 - 220 / 1310 - 1520	165 - 205 / 1130 - 1420	1 - 6	45 - 50 / 310 - 340	373 - 446	C38 - 45	30N 58 - 65	22 - 28
190 C17200	AM (TM00)	.004 - .018 / .10 - .46	100 - 110 / 685 - 755	70 - 95 / 480 - 660	16 - 30	40 - 45 / 280 - 310	210 - 251	B95 - C23	30N 37 - 44	17 - 28
	1/4 HM (TM01)	.00197 - .040 / .05 - 1.0	110 - 120 / 755 - 825	80 - 110 / 550 - 760	15 - 25	41 - 47 / 280 - 320	230 - 271	C20 - 26	30N 41 - 47	17 - 28
	1/2 HM (TM02)	.00157 - .040 / .04 - 1.0	120 - 135 / 825 - 940	95 - 125 / 650 - 870	12 - 22	42 - 48 / 290 - 330	250 - 301	C23 - 30	30N 44 - 51	17 - 28
	HM (TM04)	.00157 - .040 / .04 - 1.0	135 - 150 / 930 - 1035	110 - 135 / 750 - 940	9 - 20	45 - 52 / 310 - 360	285 - 343	C28 - 35	30N 48 - 55	17 - 28
	SHM (TM05)	.00157 - .016 / .04 - .41	150 - 160 / 1035 - 1110	125 - 140 / 860 - 970	9 - 18	47 - 55 / 320 - 380	309 - 363	C31 - 37	30N 52 - 56	17 - 28
	XHM (TM06)	.0012 - .032 / .03 - .81	155 - 175 / 1060 - 1205	135 - 170 / 930 - 1180	4 - 15	50 - 57 / 340 - 390	317 - 378	C32 - 38	30N 52 - 58	17 - 28
	XHMS (TM08)	.0012 - .063 / .03 - 1.61	175 - 190 / 1205 - 1320	150 - 180 / 1030 - 1250	3 - 12	50 - 60 / 340 - 410	325 - 413	C33 - 42	30N 53 - 62	17 - 28

BrushForm® 290 C17200	TM02	.00197 - .035	120 min.	95 - 115	14 - 30	42 - 48	225 - 309	B98 - C31	30T 81 - 30N 52	17 - 26
		.05 - .89	820 min.	650 - 800		290 - 330				
	TM03	.00197 - .035	135 min.	110 - 125	12 - 30	-	-	-	-	17 - 26
		.05 - .89	930 min.	760 - 860						
	TM04	.00197 - .035	140 min.	115 - 135	9 - 25	44 - 50	285 - 369	C28 - 38	30N 48 - 58	17 - 26
		.05 - .89	960 min.	790 - 940		300 - 340				
	TM06	.0012 - .035	155 min.	135 - 155	6 - 13	47 - 57	317 - 393	C32 - 40	30N 52 - 60	17 - 26
		.03 - .89	1060 min.	930 - 1070		320 - 390				
	TM08	.0012 - .035	175 min.	155 - 175	3 - 15	50 - 60	345 - 429	C35 - 43	30N 55 - 62	17 - 26
		.03 - .89	1200 min.	1060 - 1210		340 - 410				
Brush 60® C17460	3/4 HT	.0025 - .080	115 - 135	95 - 115	11 min.	44 - 47	220 - 280	B96 - C30	30T 81 - 30N 48	50 min.
		.063 - 2.03	795 - 930	655 - 795		300 - 320				
	HT	.0025 - .080	120 - 140	105 - 125	10 min.	42 - 45	230 - 290	B98 - C31	30T 82 - 30N 49	50 min.
		.063 - 2.03	825 - 965	720 - 860		290 - 310				
174 C17410	1/2 HT	.0025 - .080	95 - 115	80 - 100	10 - 20	40 - 45	180 - 230	B89 - 98	30T 75 - 82	50 min.
		.063 - 2.03	655 - 790	550 - 685		280 - 310				
	HT	.0025 - .080	110 - 130	100 - 120	7 - 17	40 - 45	210 - 278	B95 - 102	30T 79 - 30N 48	45 - 60
		.063 - 2.03	750 - 900	685 - 870		280 - 310				
3 C17510 and 10 C17500	AT	.0025 - .080	100 - 130	80 - 100	10 - 25	38 - 44	195 - 275	B92 - 100	30T 77 - 82	45 - 60
		.063 - 2.03	685 - 900	550 - 690		260 - 330				
	HT	.0025 - .080	110 - 135	95 - 120	8 - 20	42 - 47	216 - 287	B95 - 102	30T 79 - 83	48 - 60
		.063 - 2.03	750 - 940	650 - 830		290 - 320				
Alloy 390® C17460	HT	.0025 - .015	138 - 158	135 - 153	1 min.	35 - 40	280 - 340	C27 - 35	30N 47 - 55	44 min.
		.063 - .381	950 - 1090	930 - 1055		240 - 280				
Alloy 390E®	EHT	.0017 - .015	143 min.	138 min.	2 min.	-	300 min.	-	-	42 min.
		.043 - .381	986 min.	951 min.						

NOTE: 1) ASTM alphanumeric code for product tempers in parentheses. 2) Annealed strip is available dead soft or planished. Dead soft offers maximum deep drawing capability, but planished strip often is preferred for precision stamping. 3) Elongation applies to strip 0.004 inch (0.10mm) and thicker. 4) Consult ASTM E140, Tables 1 and 2, for proper conversion of hardness measurements. 5) Aged 3 hours at 600°F (315°C). 6). Aged 2 hours at 600°F (315°C).

Mechanical and Electrical Properties of Copper Nickel Tin Strip

Alloy	Temper[1]	Available Sizes	Tensile Strength	Yield Strength 0.2% Offset	Elongation[2]	Fatigue Strength 10^8 cycles, R=-1	Hardness[3]			Electrical Conductivity
		in / mm	ksi / MPa	ksi / MPa	%	ksi / MPa	DPH or Vickers	Rockwell	Superficial Rockwell	(%IACS)
BrushForm® 158 C72900	A (TB00)	.00197 - .15	64 - 85	25 - 45	32	-	100 - 150	B55 - 80	30T 53 - 70	7
		.05 - 3.81	440 - 590	170 - 310						
	1/4 H (TD01)	.00175 - .15	75 - 100	52 - 75	18	-	150 - 235	B80 - 99	30T 70 - 83	7
		.045 - 3.81	520 - 690	360 - 520						
	1/2 H (TD02)	.0015 - .15	85 - 110	75 - 100	8	-	190 - 275	B91 - C27	30T 77 - 30N 48	7
		.038 - 3.81	590 - 760	520 - 690						
	H (TD04)	.0012 - .15	100 - 130	95 - 125	1	-	220 - 300	B96 - C30	30T 80 - 30N 50	7
		.0305 - 3.81	690 - 900	660 - 860						
	EH (TD08)	.0012 - .15	122 - 145	115 - 135	1	-	265 - 325	C27 - 33	30N 46 - 53	7
		.0305 - 3.81	840 - 1000	790 - 930						
	AT (TX00)[4]	-	120 - 150	100 - 130	6	-	275 - 350	C26 - 36	30N 47 - 56	7
		-	830 - 1030	690 - 900						
	1/4 HT (TS01)[4]	-	130 - 160	115 - 145	4	-	290 - 365	C28 - 38	30N 49 - 57	7
		-	900 - 1100	790 - 1000						
	1/2 HT (TS02)[5]	-	145 - 175	135 - 165	3	-	315 - 390	C31 - 40	30N 51 - 60	7
		-	1000 - 1210	930 - 1140						
	HT (TS04)[5]	-	165 - 195	155 - 185	2	-	335 - 410	C34 - 42	30N 54 - 61	7
		-	1140 - 1340	1070 - 1280						
	EHT (TS08)[5]	-	175 - 205	170 - 200	1	-	370 - 450	C37 - 45	30N 57 - 64	7
		-	1205 - 1415	1170 - 1380						
	TM00	.00197 - .035	95 - 115	75 - 95	22 - 36	-	190 - 290	B91 - C29	30T 77 - 30N 50	7
		.05 - .89	660 - 790	520 - 660						
	TM02	.00197 - .035	105 - 125	90 - 110	15 - 30	-	215 - 315	B96 - C32	30T 80 - 30N 52	7
		.05 - .89	720 - 860	620 - 760						
	TM04	.00197 - .035	115 - 135	105 - 125	10 - 24	-	245 - 345	C21 - 35	30N 42 - 55	7
		.05 - .89	790 - 930	720 - 860						
	TM06	.0012 - .035	130 - 150	120 - 145	6 - 16	-	270 - 370	C25 - 38	30N 46 - 58	7
		.03 - .89	900 - 1030	830 - 1000						
	TM08	.0012 - .035	150 - 178	140 - 170	2 - 10	-	305 - 405	C30 - 42	30N 50 - 61	7
		.03 - .89	1030 - 1230	970 - 1170						
	TM10	.0012 - .035	175 - 210	165 - 195	1	-	370 - 450	C37 - 45	30N 57 - 64	7
		.03 - .89	1205 - 1450	1140 - 1345						

BrushForm® 96 C72700	A (TB00)	.00197 - .15 .05 - 3.81	60 typ 414 typ	37 typ 255 typ	30	-	100 - 150	B55 - 80	30T 53 - 70	7
	1/4 H (TD01)	.00175 - .15 .045 - 3.81	75 typ 517 typ	53 typ 365 typ	16	-	125 min	B70 min	30T 63 min	7
	1/2 H (TD02)	.0015 - .15 .038 - 3.81	85 typ 586 typ	67 typ 462 typ	8	-	-	-	-	7
	H (TD04)	.0012 - .15 .0305 - 3.81	100 typ 689 typ	88 typ 607 typ	3	-	175 - 275	B88 - C27	30T 75 - 30N 48	7
	EH (TD08)		110 typ 758 typ	92 typ 634 typ	-	-	-	-	-	7
	AT (TX00)[6]	- -	100 typ 689 typ	75 typ 517 typ	15	-	250 - 340	C23 - 35	30N 44 - 55	10
	1/4 HT (TS01)[6]	- -	115 typ 793 typ	90 typ 621 typ	10	-	230 - 330	C20 - 34	30N 41 - 54	10
	1/2 HT (TS02)[6]	- -	125 typ 862 typ	100 typ 689 typ	6	-	280 - 330	C27 - 34	30N 48 - 54	10
	HT (TS04)[6]	- -	135 typ 931 typ	120 typ 827 typ	4	-	300 - 370	C30 - 38	30N 50 - 58	10
	TM00	.00197 - .035 .05 - .89	98 typ 676 typ	60 typ 414 typ	16	-	180 - 280	B89 - C28	30T 75 - 30N 48	10
	TM02	.00197 - .035 .05 - .89	105 typ 724 typ	75 typ 517 typ	15	-	200 - 300	B93 - C30	30T 78 - 30N 51	10
	TM04	.00197 - .035 .05 - .89	110 typ 758 typ	90 typ 621 typ	8	-	230 - 300	B98 - C30	30T 81 - 30N 51	10
	TM06	.0012 - .035 .03 - .89	120 typ 827 typ	100 typ 689 typ	4	-	240 - 360	C21 - 37	30N 42 - 56	10
	TM08	.0012 - .035 .03 - .89	130 typ 896 typ	110 typ 758 typ	-	-	260 - 380	C24 - 39	30N 45 - 58	10

NOTE: 1) ASTM alphanumeric code for product tempers in parentheses. 2) Elongation applies to strip 0.004 inch (0.10mm) and thicker. 3) Consult with ASTM E140,Tables 1 and 2, for proper conversion of hardness measurements. 4)Aged 3 hours at 700°F (370°C). 5) Aged 3 hours at 650°F (345°C). 6) Aged 2 hours at 700°F (370°C).

Mechanical and Electrical Properties of Nickel Beryllium Strip

Alloy	Temper [1]	Available Sizes	Tensile Strength	Yield Strength 0.2% Offset	Elongation [2]	Fatigue Strength 10^8 cycles, R=-1	Hardness [3]			Electrical Conductivity
		in / mm	ksi / MPa	ksi / MPa	%	ksi / MPa	DPH or Vickers	Rockwell	Superficial Rockwell	(%IACS)
360 N03360	A	.00197 - .032	95 - 130	40 - 70	30 min.	-	106 - 200	B50 - 39	-	4
		.05 - .81	660 - 900	280 - 480						
	1/4 H	.00197 - .032	110 - 150	65 - 125	15 min.	-	153 - 293	B85 - 94	-	4
		.05 - .81	760 - 1030	450 - 860						
	1/2 H	.00197 - .032	130 - 175	115 - 170	4 min.	-	160 - 383	B83 - C40	-	4
		.05 - .81	900 - 1210	790 - 1170						
	H	.00197 - .032	155 - 190	150 - 190	1 min.	-	180 - 491	B90 - C49	-	4
		.05 - .81	1070 - 1310	1030 - 1310						
	AT[4]	-	215 min.	150 min.	12 min.	125 - 150 [6]	343 - 528	-	15N78 - 86	6
		-	1480 min.	1030 min.		860 - 1030 [6]				
	1/4 HT[4]	-	230 min.	175 min.	10 min.	120 - 145 [6]	383 - 598	-	15N80 - 88	6
		-	1590 min.	1210 min.		830 - 1000 [6]				
	1/2 HT[5]	-	245 min.	200 min.	9 min.	120 - 145	395 - 695	-	15N81 - 90	6
		-	1690 min.	1380 min.		830 - 1000 [6]				
	HT[5]	-	270 min.	230 min.	8 min.	115 - 140 [6]	446 - 695	-	15N83 - 90	6
		-	1860 min.	1590 min.		790 - 970 [6]				
	MH2	.00197 - .032	155 - 180	100 - 125	14 min.	-	-	-	-	5
		.05 - .81	1070 - 1240	690 - 860						
	MH4	.00197 - .032	180 - 205	120 - 155	12 min.	125 - 150 [6]	-	-	-	5
		.05 - .81	1240 - 1410	830 - 1070		860 - 1030 [6]				
	MH6	.00197 - .032	200 - 225	150 - 175	10 min.	-	-	-	-	5
		.05 - .81	1380 - 1550	1030 - 1210						
	MH8	.00197 - .032	220 - 245	170 - 205	9 min.	110 - 135 [6]	-	-	-	5
		.05 - .81	1520 - 1690	1170 - 1410		760 - 930 [6]				
	MH10	.00197 - .032	240 - 270	200 - 225	8 min.	-	-	-	-	5
		.05 - .81	1660 - 1860	1380 - 1550						
	MH12	.00197 - .032	260 - 290	220 - 245	8 min.	115 - 140 [6]	-	-	-	5
		.05 - .81	1790 - 2000	1520 - 1690		790 - 970 [6]				

NOTE: 1) ASTM alphanumeric code for product tempers in parentheses. 2) Elongation applies to strip 0.004 inch (0.10 mm) and thicker. 3) Consult with ASTM E140, Tables 1 and 2, for proper conversion of hardness measurements. 4) Aged 2.5 hours at 925°F (510°C). 5) Aged 1.5 hours at 925°F (510°C). 6) Estimated from limited medium cycle data and known high and low cycle fatigue behavior of 1/2 HT temper.

Spring Bend Limits of Strip Alloys

Spring bend limit is a measure of how much bending stress can be applied to the strip without creating permanent set. Unlike yield strength, it is a function of thickness of the input strip.

Copper beryllium strip produced and sold under the relevant DIN/EN or JIS specifications meet the spring bend limits as described in the table below.

Spring Bend Limit of Copper Beryllium Strip

Alloy	Temper[1]	Per DIN EN 12384		Per JIS H3130
		Thickness = 0.004 - 0.010" 0.1 - 0.25 mm	Thickness = 0.010 - 0.040" 0.25 - 1.0 mm	Thickness = 0.008 - 0.063" 0.2 - 1.6 mm
		(ksi)	(ksi)	(ksi)
		(MPa)	(MPa)	(MPa)
25 C17200	AT (TF00)[2]	113 min.	120 min.	106 min.
		780 min.	830 min.	735 min.
	1/4 HT (TH01)[3]	119 min.	132 min.	121 min.
		820 min.	910 min.	835 min.
	1/2 HT (TH02)[3]	128 min.	142 min.	128 min.
		880 min.	980 min.	885 min.
	HT (TH04)[3]	133 min.	148 min.	135 min.
		920 min.	1020 min.	930 min.
190 C17200	AM (TM00)	58 min.	59 min.	57 min.
		400 min.	410 min.	390 min.
	1/4 HM (TM01)	70 min.	73 min.	64 min.
		480 min.	500 min.	440 min.
	1/2 HM (TM02)	77 min.	84 min.	78 min.
		530 min.	580 min.	540 min.
	HM (TM04)	87 min.	96 min.	92 min.
		600 min.	660 min.	635 min.
	SHM (TM05)	97 min.	106 min.	-
		670 min.	730 min.	-
	XHM (TM06)	110 min.	122 min.	-
		760 min.	840 min.	-
	XHMS (TM08)	113 min.	126 min.	-
		780 min.	870 min.	-
Brush 60® C17460	3/4 HT	87 min.	102 min.	-
		600 min.	700 min.	-
	HT	90 min.	106 min.	-
		610 min.	730 min.	-
174 C17410	1/2 HT	77 min.	91 min.	-
		530 min.	630 min.	-
	HT	84 min.	99 min.	-
		580 min.	680 min.	-
3 C17510	AT	54 min.	54 min.	-
		370 min.	370 min.	-
	HT	73 min.	77 min.	-
		500 min.	530 min.	-

NOTE: 1) ASTM alphanumeric code for product tempers in parentheses. 2) Aged 3 hours at 600°F (315°C). 3) Aged 2 hours at 600°F (315°C).

Wire

Wire is one of the most versatile copper beryllium product forms with no other product having applications based on as many diverse attributes.

Applications of round wire include:

- Miniature machined electronic sockets
- Long travel coil springs
- Cold headed fasteners
- Spring loaded test probes
- Lightweight, fatigue resistant stranded cable
- Braided shielding cloth
- Corrosion and biofouling resistant marine wire and wire mesh structures
- Eyeglass frames

Wire is available with cross sections other than round. "Shaped" wire plays an important role in specialized applications. For example, flat wire is used in retractable antennas and telecommunication cables. Flat wire also can be used in place of narrow slit strip. Although there is a width to thickness ratio above which flat wire is impractical, many times a savings is realized. Flat wire has no slitting burrs.

Wire Specifications[1]

Brush Alloy	UNS Number	Current	Withdrawn/ Superseded[2]
25	C17200	ASTM B 197, AMS 4725 SAE J 461, 463 JIS H3270, EN 1654, 12166, GB5233, 3134	QQ-C-530 DIN 17666, 17682 NF A 51-114 UNE 37-103, 37-110 MIL-C-6941
M25	C17300	ASTM B 197 EN 12164, 12166	QQ-C-530 NF A 51-114
3	C17510	EN 12167, 12166	ISO 1187, 1638
10	C17500	EN 12167, 12166	DIN 17666, 17682 ISO 1187, 1638
ToughMet® 3	C72900	-	-
Brush 1915®	C19150	ASTM B 740	-

ASTM	American Society for Testing and Materials
SAE	Society of Automotive Engineers
AMS	Aerospace Materials Specification (published by SAE)
EN	Comité Européen de Normalisation (Europe)
GB	Standardization Administration of China
QQ	US Federal Specification
MIL	US Military Specification
ISO	International Standards Organization
DIN	Deutsches Institut fur Normung (Germany)
NF	Association Française de Normalisation (France)
UNE	Instituto Español de Normalización (Spain)

NOTE: 1) Unless otherwise specified, material will be produced to ASTM specifications. 2) Withdrawn and superseded specifications are listed for reference only, and are not to be used for purchasing. Please contact Materion Brush Performance Alloys to determine the appropriate replacement specification.

Square wire is used in electronic contacts especially where wire wrapping requires sharp corners for reliable contact. Occasionally square or rectangular wire requires a beveled corner for orientation. These and other less common shape requirements can be met with copper beryllium wire.

Materion Brush Performance Alloys supplies wire in diameters from 0.500 inch (12.7 mm) down to 0.050 inch (1.27 mm) with tolerances shown in the table on this page. Finer wire can be supplied either by special order from Materion Brush Performance Alloys or from any one of a number of copper beryllium wire redrawers.

Wire is supplied annealed (A), quarter hard (1/4H), half hard (1/2H), or full hard (H) tempers. In special cases however, prehardened (also called "pretempered") wire is available. This product offers versatility in strength and durability for products with mild to somewhat stringent forming requirements.

Wire is supplied in coil form on spools or reels. Wire that is straightened and cut to length is called rod, although only the tempers recognized by ASTM are available as standard product. (See tables on page 29 in the Rod, Bar and Tube section of this Guide.) Non-standard tempers such as ¼ H or ½ H can be produced upon request if the customer provides the desired property ranges.

Wire Tolerance

(inches) (plus or minus)

Wire Diameter		Brush Standard Diameter Tolerance	
Over	Including	Cold Drawn	Annealed
0.0300	0.0800	0.0003	0.001
0.0800	0.1250	0.0004	0.002
0.1250	0.2500	0.0006	0.002
0.2500	0.3125	0.0007	0.002
0.3125	0.4060	0.0010	0.002
0.4060	0.5000	0.0010	0.002

(mm) (plus or minus)

Wire Diameter		Brush Standard Diameter Tolerance	
Over	Including	Cold Drawn	Annealed
0.8	1.5	0.01	0.03
1.5	2.0	0.01	0.03
2.0	3.8	0.02	0.05
3.8	12.0	0.03	0.05

NOTE: Additional tolerances are per ASTM B 250. Please specify the exact tolerances that you require when you place your order. Tighter tolerances may be available at additional cost. Please contact your local sales engineer to confirm the requested capability.

Mechanical and Electrical Properties of Wire Products

Alloy	Temper[1]	Heat Treatment Specification	Wire Diameter	Tensile Strength	Yield Strength 0.2% Offset	Elongation	Electrical Conductivity
			in	ksi	ksi	Percent	(%IACS)
			mm	MPa	MPa		
25 C17200 and M25 C17300 (leaded)	A (TB00)	3 hr 600 - 625 °F	0.050 - 0.500	60 - 82	20 - 30	30 - 75	15 - 19
		3 hr 315 - 330 °C	1.3 - 12.7	410 - 565	130 - 210		
	1/4 H (TD01)	2 hr 600 - 625 °F	0.050 - 0.500	90 - 115	75 - 105	3 - 25	15 - 19
		2 hr 315 - 330 °C	1.3 - 12.7	620 - 800	510 - 730		
	1/2 H (TD02)	1.5 hr 600 - 625 °F	0.050 - 0.500	110 - 135	90 - 125	2 - 15	15 - 19
		1.5 hr 315 - 330 °C	1.3 - 12.7	750 - 940	620 - 870		
	3/4 H (TD03)	1 hr 600 - 625 °F	0.050 - 0.1875	130 - 155	115 - 150	2 - 8	15 - 19
		1 hr 315 - 330 °C	1.3 - 4.8	890 - 1070	790 - 1040		
	H (TD04)	1 hr 600 - 625 °F	0.050 - 0.1875	140 - 165	130 - 160	1 - 6	15 - 19
		1 hr 315 - 330 °C	1.3 - 4.8	960 - 1140	890 - 1110		
	AT (TF00)	-	0.050 - 0.500	160 - 200	145 - 180	3 min.	22 - 28
			1.3 - 12.7	1100 - 1380	990 - 1250		
	1/4 HT (TH01)	-	0.050 - 0.500	175 - 210	165 - 200	2 min.	22 - 28
			1.3 - 12.7	1200 - 1450	1130 - 1380		
	1/2 HT (TH02)	-	0.050 - 0.500	185 - 215	170 - 210	2 min.	22 - 28
			1.3 - 12.7	1270 - 1490	1170 - 1450		
	3/4 HT (TH03)	-	0.050 - 0.080	190 - 230	175 - 220	2 min.	22 - 28
			1.3 - 2.0	1310 - 1590	1200 - 1520		
	HT (TH04)	-	0.050 - 0.080	195 - 230	180 - 220	1 min.	22 - 28
			1.3 - 2.0	1340 - 1590	1240 - 1520		
3 C17510 and 10 C17500	A (TB00)	3 hr 900 - 925 °F	0.050 - 0.500	35 - 55	10 - 30	20 - 60	20 - 30
		3 hr 480 - 495 °C	1.3 - 12.7	240 - 380	60 - 210		
	H (TD04)	2 hr 900 - 925 °F	0.050 - 0.500	65 - 80	55 - 75	2 - 20	20 - 30
		2 hr 480 - 495 °C	1.3 - 12.7	440 - 560	370 - 520		
	AT (TF00)	-	0.050 - 0.500	100 - 130	80 - 110	10 min.	45 - 60
			1.3 - 12.7	680 - 900	550 - 760		
	HT (TH04)	-	0.050 - 0.500	110 - 140	95 - 125	10 min.	48 - 60
			1.3 - 12.7	750 - 970	650 - 870		
Brush 1915® C19150 (leaded) and 1916 C19160 (leaded)	A (TB00)	3 hr 900 - 925 °F	0.030 to 0.625	25 - 50	5 - 25	40 - 60	-
		3 hr 480 - 495 °C	0.76 to 15.9	170 - 350	35 - 170		
	H (TD04)	3 hr 900 - 925 °F	0.030 to 0.4375	50 - 75	35 - 65	1 - 20	-
		3 hr 480 - 495 °C	0.76 to 11.1	350 - 520	240 - 450		
		3 hr 900 - 925 °F	0.4375 to 0.625	40 - 65	25 - 55	1 - 20	-
		3 hr 480 - 495 °C	11.1 to 15.9	280 - 450	170 - 380		
	AT (TF00)	-	0.030 to 0.625	50 - 70	25 - 50	25 - 45	50 min.
			0.76 to 15.9	350 - 480	170 - 350		
	HT (TH04)	-	0.030 to 0.4375	80 - 105	70 - 100	4 - 30	50 min.
			0.76 to 11.1	560 - 720	480 - 690		
			0.4375 to 0.625	75 - 105	65 - 90	4 - 30	50 min.
			11.1 to 15.9	520 - 720	450 - 620		
ToughMet® 3 C72900	TS 160U	-	0.030 to 0.25	160 min.	150 min.	5 min.	-
			0.76 to 6.35	1100 min.	1034 min.		
			0.25 - 0.40	160 min.	150 min.	7 min.	-
			6.35 - 10	1100 min.	1034 min.		

NOTE: 1) ASTM alphanumeric code for tempers.

Rod, Bar, Tube and Plate Temper Designations

As is the case for strip and wire, copper beryllium alloys in the form of rod, bar, plate and tube use the ASTM B 601 temper designations. The solution annealed temper is designated by the letter "A", while solution annealed and cold drawn material is designated by the letter "H". The suffix "T" is added to each of these tempers to signify that they have been precipitation age hardened.

The other alloys listed on this page also achieve their properties through a variety of proprietary solution annealing, cold work and age hardening. These temper designations are unique to these product families, and do not follow the standard ASTM B 601 guidelines. The meaning of these temper designations is explained in the table below.

Rod, Bar, Tube and Plate Temper Designations

Brush Designation	ASTM Designation	Description
A H	TB00 TD04	Solution Annealed Solution Annealed then cold drawn to Full Hard
AT HT	TF00 TH04	The suffix "T" added to temper designations indicates that the material has been age hardened by the standard heat treatment.
CX 90 CX 105	- -	Cast and spinodally hardened to specific property ranges, no further heat treatment is required, **ToughMet® only.**
AT 90 AT 110	TX00 TX00	Cast, worked, and spinodally hardened to specific property ranges, no further heat treatment is required, **ToughMet® only.**
TS 120U TS 150 TS 160U	TXTS TXTS TXTS	Cast, worked, and spinodally hardened to specific property ranges, no further heat treatment is required, **ToughMet® only.**
-	TQ50	Cast, quench hardened and temper annealed, **95510 only.**
HH LH XL V	-	Mill hardened to specific property ranges. **MoldMAX® only.**

Rod and Bar

Standard lengths from one inch to twelve feet (25 mm to 3.7 m); sections from 3/8 inch to more than 9 inches (9.5 to 230 mm); precision and versatility from cold drawing and extrusion; simplicity of age hardening; strength, corrosion resistance, machinability... these are just a few of the useful features that make rod and bar unique.

Rod is supplied in straight lengths for machining or forming into finished components by the user. Forming is done before age hardening and machining usually after hardening. Typical applications include:

- Female circular and coaxial connectors
- Test probes and compression contacts
- Low maintenance bearings and bushings
- Resistance welding gun structural components
- Core pins and other inserts for plastic injection molding and metal die casting

Bar is also produced in straight lengths, but has a cross section other than round. Square and rectangular are the most common.

Applications include :

- Anti-galling wear plates
- Guide rails and bus bars
- Machined threaded fasteners
- Die inserts for resistance welding

An important use of rod and bar is in products for resistance welding applications. Copper beryllium fills the needs of this industry by providing hardness and electrical conductivity for precision in structural components and durability in electrodes. Ease of fabrication in bending and machining also contributes to cost effective resistance welding.

Copper beryllium rods and bars are available in the as annealed (A), cold drawn (H), annealed and precipitation hardened (AT), and annealed, cold drawn and precipitation hardened (HT) tempers, as shown in the table on page 24.

Rod and Bar Specifications[1]

Brush Alloy	UNS Number	Current	Withdrawn/ Superseded[2]
25	C17200	ASTM B 196 MIL-C-21657 SAE J 461, 463 AMS 4533, 4534, 4650, 4651 BMS 7-353 Type 2 RWMA Class 4 JIS H 3270 EN 1654, 12163, 12165, 12167 GB 5233, 4431	QQ-C-530 DIN 17666, 17672 NF A 51-114 UNE 37-103, 37-149 MIL-C-6941
M25	C17300	ASTM B 196 MIL-C-21657 EN 12164	QQ-C-530 DIN 17666, 17672 NF A 51-114
165	C17000	ASTM B 196 SAE J 461, 463 RWMA Class 4	-
3	C17510	ASTM B 441 SAE J 461, 463 RWMA Class 3 EN 12163, 12165, 12167	DIN 17666, 17672 ISO 1187, 1637
10	C17500	ASTM B 441 SAE J 461, 463 RWMA Class 3 EN 12163, 12165, 12167	BS 2872, 2874 DIN 17666, 17672 ISO 1187, 1637 MIL-C-46087 UNE 37-103, 37-149
310	-	RWMA Class 3	-
Brush 1915®	C19150	-	-
1916	C19160	-	-
C18000	C18000	RWMA Class 3	-
ToughMet® 3	C72900	ASTM B 929 AMS 4596, 4597 AIMS 02-04-002 ABS 5152 (pending) BMS 7-373 Classes 90, 100 and TS MTL 4112	-
	C96900	ASTM B 505	-

ASTM	American Society for Testing and Materials
SAE	Society of Automotive Engineers
AMS	Aerospace Materials Specification (published by SAE)
EN	Comité Européen de Normalisation (Europe)
JIS	Japanese Industrial Standard (Japan)
GB	Standardization Administration of China
BMS	Boeing Material Specification
AIMS	Airbus Industries Material Specification
RWMA	Resistance Welders Manufacturer's Association
MIL	US Military Specification
QQ	US Federal Specification
ISO	International Standards Organization
DIN	Deutsches Institut fur Normung (Germany)
BS	British Standard (UK)
NF	Association Française de Normalisation (France)
UNE	Instituto Español de Normalización (Spain)

NOTE: 1) Unless otherwise specified, material will be produced to ASTM specifications. 2) Withdrawn and superseded specifications are listed for reference only, since they may appear on older drawings. They are not to be used for purchasing. Contact Materion Brush Performance Alloys sales to determine the appropriate replacement specification.

The precipitation hardened tempers of copper beryllium are only available in diameters of 0.4375 inches (12.0 mm) or greater. Smaller diameter rod cannot be heat treated and still maintain straightness. Rod less than this diameter must be purchased in the heat treatable tempers, and then must be heat treated after machining.

Note that in Alloys 25 and 165, the material will shrink during age hardening. Linear dimensions will decrease by about 0.2%, and there is potential for distortion. If exceptionally tight tolerances are required, it is best to rough machine, heat treat, and then finish machine to final dimensions.

Other tempers not recognized by ASTM can be custom fabricated, but the customer must clearly define the expected properties at the time of order.

The other high performance alloy products are available in the proprietary, customized tempers, as shown in the tables on pages 24 and 25.

The MoldMAX® and PROtherm™ alloys are tabulated separately on page 31 in the plastic tooling alloy section.

Rod and Bar Tolerance

Product	Diameter (inches)		Brush Standard Diameter Tolerance (plus or minus)	Standard Tolerance Out of Round
	Over	Including		
Cold Drawn CuBe	0.0300	0.0800	0.0003	0.0003
	0.0800	0.1250	0.0004	0.0004
	0.1250	0.2500	0.0006	0.0004
	0.2500	0.3125	0.0007	0.0007
	0.3125	0.3750	0.001	0.001
	0.375	0.500	0.002	-
	0.500	1.00	0.003	-
	1.00	2.00	0.004	-
	2.00	3.00	0.2% of size	-
Hot Worked CuBe	0.750	1.25	0.020	-
	1.25	2.50	0.030	-
	2.50	6.00	0.060	-
ToughMet® CX and AT		1	+0.040 / -0	-
	1.00	2.00	+0.060 / -0	-
	2.00	3.00	+0.100 / -0	-
	3.00	3.50	+0.140 / -0	-
	3.50	4.00	+0.240 / -0	-

Product	Diameter (mm)		Brush Standard Diameter Tolerance (plus or minus)	Standard Tolerance Out of Round
	Over	Including		
Cold Drawn CuBe	0.76	2.0	0.008	0.008
	2.0	3.2	0.010	0.010
	3.2	6.4	0.015	0.010
	6.4	7.9	0.018	0.018
	7.9	9.5	0.025	0.025
	9.5	12.0	0.05	-
	12.0	25.0	0.08	-
	25.0	50.0	0.10	-
	50.0	75.0	0.2% of size	-
Hot Worked CuBe	20	30	0.50	-
	30	38	0.75	-
	38	150	1.50	-
ToughMet® CX and AT		25	+0.50 / -0	-
	25	50	+0.75 / -0	-
	50	75	+1.3 / -0	-
	75	90	+1.8 / -0	-
	90	100	+3.0 / -0	-

NOTE: Additional tolerance are per ASTM B 249 (rod and bar) or ASTM B 570 (forgings and extrusions), depending on the product form. Please specify the exact tolerances that you require when you place your order. Tighter tolerances may be available at additional cost. Please contact your local sales engineer to confirm the requested capability.

Mechanical and Electrical Properties of Rod and Bar Products

Alloy	Temper[1]	Heat Treatment Specification	Outer Diameter (Rod) or Thickness (Bar)	Tensile Strength	Yield Strength 0.2% Offset	Elongation	Rockwell Hardness	Electrical Conductivity
			in	ksi	ksi	Percent	B or C Scale	Percent IACS
			mm	MPa	MPa			
25 C17200 and M25[2] C17300 (leaded)	A (TB00)	3 hr 600 - 675 °F	0.030 to 14	60 - 85	20 - 35	20 - 75	B45 - 85	15 - 20
		3 hr 315 - 357 °C	0.76 to 355.6	410 - 590	130 - 250			
	H (TD04)	2 - 3 hr 600 - 675 °F	0.030 to 3/8	90 - 130	75 - 105	8 - 30	B88 - 103	15 - 20
		2 - 3 hr 315 - 357 °C	0.76 to 9.5	620 - 900	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 3/8 to 1	90 - 125	75 - 105	8 - 30	B88 - 102	15 - 20
		2 - 3 hr 315 - 357 °C	Over 9.5 to 25.4	620 - 860	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 1 to 3	85 - 120	75 - 105	8 - 20	B88 - 101	15 - 20
		2 - 3 hr 315 - 357 °C	Over 25.4 to 76	590 - 830	520 - 720			
	AT (TF00)	-	0.030 to 3	165 - 200	145 - 175	4 - 10	C36 - 42	25 - 30
			0.76 to 76	1140 - 1380	1000 - 1210			
			Over 3 to 14	165 - 200	130 - 175	3 - 10	C36 - 42	25 - 30
			Over 76 to 355.6	1140 - 1380	900 - 1210			
	HT (TH04)	-	0.030 to 3/8	185 - 225	160 - 200	2 - 9	C39 - 45	25 - 30
			0.76 to 9.5	1280 - 1550	1103 - 1380			
			Over 3/8 to 1	180 - 220	155 - 195	2 - 9	C38 - 44	25 - 30
			Over 9.5 to 25.4	1240 - 1520	1070 - 1340			
			Over 1 to 3	175 - 215	145 - 190	4 - 9	C37 - 44	25 - 30
			Over 25.4 to 76	1210 - 1480	1000 - 1310			
165 C17000	A (TB00)	3 hr 600 - 675 °F	0.030 to 14	60 - 85	20 - 35	20 - 60	B45 - 85	15 - 20
		3 hr 315 - 357 °C	0.76 to 355.6	410 - 590	130 - 250			
	HT (TH04)	2 - 3 hr 600 - 675 °F	0.030 to 3/8	90 - 130	75 - 105	8 - 30	B92 - 103	15 - 20
		2 - 3 hr 315 - 357 °C	0.76 to 9.5	620 - 900	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 3/8 to 1	90 - 125	75 - 105	8 - 30	B91 - 102	15 - 20
		2 - 3 hr 315 - 357 °C	Over 9.5 to 25.4	620 - 860	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 1 to 3	85 - 120	75 - 105	8 - 20	B88 - 101	15 - 20
		2 - 3 hr 315 - 357 °C	Over 25.4 to 76	590 - 830	520 - 720			
	AT (TF00)	-	0.030 to 3	150 - 190	125 - 155	4 - 10	C32 - 39	25 - 30
			0.76 to 76	1030 - 1310	860 - 1070			
			Over 3 to 14	150 - 190	125 - 155	3 - 10	C32 - 39	25 - 30
			Over 76 to 355.6	1030 - 1310	860 - 1070			
	HT (TH04)	-	0.030 to 3/8	170 - 210	145 - 185	2 - 5	C35 - 41	25 - 30
			0.76 to 9.5	1170 - 1450	1000 - 1280			
			Over 3/8 to 1	170 - 210	145 - 185	2 - 5	C35 - 41	25 - 30
			Over 9.5 to 25.4	1170 - 1450	1000 - 1280			
			Over 1 to 3	165 - 200	135 - 175	4 - 9	C34 - 39	25 - 30
			Over 25.4 to 76	1140 - 1380	930 - 1210			
3 C17510 and 10 C17500	A (TB00)	3 hr 850 - 900 °F	0.030 to 10	35 - 55	10 - 30	20 - 35	B20 - 50	20 - 30
		3 hr 450 - 480 °C	0.76 to 254	240 - 380	70 - 210			
	H (TD04)	2 hr 850 - 900 °F	0.030 to 3	65 - 80	50 - 75	10 - 15	B60 - 80	20 - 30
		2 hr 450 - 480 °C	0.76 to 76	450 - 550	350 - 520			
	AT (TF00)	-	0.030 to 10	100 - 130	80 - 100	10 - 25	B92 - 100	45 - 60
			0.76 to 254	690 - 900	550 - 690			
	HT (TH04)	-	0.030 to 3	110 - 140	95 - 125	5 - 25	B95 - 102	48 - 60
			0.76 to 76	760 - 970	660 - 860			
310[3]	AT (TF00)	-	0.87 to 8	104 - 119	96 - 107	10 - 14	BHN 230 (B98) min.	45
			22 to 203	720 - 820	660 - 740			
	HT (TH04)	-	0.23 to 0.95	104 - 119	96 - 107	10 - 14	BHN 230 (B98) min.	45
			5.8 to 24.1	720 - 820	660 - 740			

NOTE: 1) ASTM alphanumeric code for tempers. These are the tempers recognized by ASTM. Tempers not recognized by ASTM available as a custom order, but the customer and Materion Brush Performance Alloys must first agree what properties are expected. 2) M25 rod available only in diameters equal to or less than 1.875" (48 mm) 3) Alloy 310 tempers either AT (TF00) or HT (TH04) depending on size and shape.

Mechanical and Electrical Properties of Rod and Bar Products

Alloy	Temper[1]	Heat Treatment Specification	Outer Diameter (Rod) or Thickness (Bar)	Tensile Strength	Yield Strength 0.2% Offset	Elongation	Rockwell Hardness	Electrical Conductivity
			in	ksi	ksi	Percent	B or C Scale	Percent IACS
			mm	MPa	MPa			
ToughMet® 2 C96970	CX 90	-	2.0 to 12	105 min.	90 min.	3 min.	C27 min.	13 - 14
			51 to 305	720 min.	620 min.			
ToughMet® 3 C96900	CX 90	-	1.0 to 3.5	105 min.	90 min.	6 min.	C27 min.	7 - 8
			25.4 to 89	720 min.	620 min.			
	CX 105	-	1.0 to 3.5	110 min.	105 min.	4 min.	C30 min.	7 - 8
			25.4 to 89	760 min.	720 min.			
ToughMet® 3 C72900	AT 90 (TX00)	-	1.0 to 4	110 min.	90 min.	15 min.	C26 min.	7 - 8
			25.4 to 100	760 min.	620 min.			
			4.0 to 9	110 min.	90 min.	12 min.	C26 min.	7 - 8
			100 to 228.6	760 min.	620 min.			
	AT 110 (TX00)	-	0.595 to 4	132 min.	110 min.	10 min.	C30 min.	7 - 8
			15.1 to 100	910 min.	760 min.			
			4 to 9	127 min.	110 min.	6 min.	C30 min.	7 - 8
			100 to 228.6	875 min.	760 min.			
ToughMet® 3 C72900	TS 120U (TXTS)	-	0.5 to 3.25	120 min.	110 min.	15 min.	C23 min.	7 max.
			19 to 82	825 min.	755 min.			
	TS 160U (TXTS)	-	0.125 to 0.25	160 min.	150 min.	5 min.	C32 min.	7 max.
			3.175 to 6.35	1100 min.	1035 min.			
			0.25 to 0.4	160 min.	150 min.	7 min.	C32 min.	7 max.
			6.35 to 10	1100 min.	1035 min.			
			0.4 to 0.75	165 min.	150 min.	7 min.	C36 min.	7 max.
			10 to 19	1138 min.	1034 min.			
			0.75 to 1.6	165 min.	150 min.	5 min.	C34 min.	7 max.
			19 to 41	1138 min.	1034 min.			
			1.6 to 3.25	160 min.	150 min.	3 min.	C34 min.	7 max.
			41 to 82	1105 min.	1034 min.			
C18000	AT (TF00)	-	1.0 to 14	90	70	14	B90 min.	45 min.
			25.4 to 355.6	620	480			
	HT (TH04)	-	0.625 to 1.0	95	75	14	B92 min.	45 min.
			16 to 25.4	660	520			
Brush 1915® C19150 (leaded) and 1916 C19160 (leaded)	A (TB00)	3 hr 900 - 925 °F	0.030 to 0.625	30 - 50	10 - 40	35 - 55	-	-
		3 hr 480 - 495 °C	0.76 to 15.9	210 - 350	70 - 280			
	H (TD04)	3 hr 900 - 925 °F	0.030 to 0.4375	55 - 75	45 - 70	1 - 20	-	-
		3 hr 480 - 495 °C	0.76 to 11.1	380 - 520	310 - 480			
		3 hr 900 - 925 °F	0.4375 to 0.625	40 - 65	25 - 55	1 - 20	-	-
		3 hr 480 - 495 °C	11.1 to 15.9	280 - 450	170 - 380			
	AT (TF00)	-	0.030 to 0.625	50 - 70	25 - 50	20 - 45	-	50 min.
			0.76 to 15.9	350 - 480	170 - 350			
	HT (TH04)	-	0.030 to 0.4375	85 - 105	70 - 95	4 - 30	-	50 min.
			0.76 to 11.1	590 - 720	480 - 660			
			0.4375 to 0.625	70 - 100	55 - 85	4 - 30	-	50 min.
			11.1 to 15.9	480 - 690	380 - 590			
FormaMet®	-	-	1.57 to 11.8	-	-	<0.5%	C39	6
			40 to 300					

NOTE: 1) ASTM alphanumeric code for tempers. These are the tempers recognized by ASTM. Tempers not recognized by ASTM are available as a custom order, but the customer and Materion Brush Performance Alloys must first agree what properties are expected.

Tube

Tube comes in a wide range of diameter/wall thickness combinations. These range from the ultra thin wall configurations produced by tube redrawing specialists, to light wall cold drawn tube, to heavy wall hot worked or cast product. Typical applications include:

- High strength instrument tubes such as bourdon and pitot tubes (redrawn tube)
- Bearings for aircraft landing gear and pivoting members
- Bushings and bearings for off-road equipment and industrial machinery
- Long life tri-cone drilling bit bushings
- Pressure housings for precision magnetometers and other instruments

For most alloys, the available wall thickness is about 10 to 20% of the outer diameter, subject to certain minimum and maximum constraints. Please see the accompanying charts on page 28 for more information on available diameters and wall thicknesses.

Tube Tolerance

Product	Diameter (inches)		Brush Standard Diameter Tolerance (plus or minus)
	Over	Including	
Cold Drawn	0.375	0.500	0.002
	0.500	1.00	0.003
	1.00	2.00	0.004
	2.00	3.00	0.2% of size
As Extruded	0.750	1.25	0.020
	1.25	2.50	0.030
	2.50	6.00	0.060
	> 6.00	-	0.060

Product	Diameter (mm)		Brush Standard Diameter Tolerance (plus or minus)
	Over	Including	
Cold Drawn	3.8	12	0.05
	12	25	0.08
	25	50	0.10
	50	75	0.2% of size
As Extruded	20	30	0.50
	30	38	0.75
	38	150	1.50
	> 150	-	1.50

NOTE: Additional tolerance are per ASTM B 251 (wrought tube), ASTM B 271(centrifugal cast tube) or ASTM B 505 (continuous cast tube), depending on the product form. Please specify the exact tolerances that you require when you place your order. Tighter tolerances may be available at additional cost. Please contact your local sales engineer to confirm the requested capability.

Sizes outside these ranges are available from a variety of reprocessors. Small diameter and very thin walled tubes can be produced in seamless form by tube redrawers, or they can be made by rolled and welded strip. Very large rings can be produced by forging processes. Please contact Materion Brush Performance Alloys for direction to the appropriate resource.

Tube Specifications[1]

Brush Alloy	UNS Number	Current	Withdrawn/ Superseded[2]
25	C17200	ASTM B 251, B 643 MIL-C-21657 SAE J 461, 463 AMS 4535 BMS 7-353 Type 2 RWMA Class 4 JIS H 3270 EN 1654, 12163, 12165, 12167 GB 5233, 4431	QQ-C-530 DIN 17666, 17672 NF A 51-114 UNE 37-103, 37-149
165	C17000	SAE J 461, 463 RWMA Class 4	-
3	C17510	ASTM B 937, ASTM B 944, SAE J 461, 463 RWMA Class 3 EN 12163, 12165, 12167	DIN 17666, 17672 ISO 1187, 1637
10	C17500	ASTM B 937 SAE J 461, 463 RWMA Class 3 EN 12163, 12165, 12167	BS 2872, 2874 DIN 17666, 17672 ISO 1187, 1637 UNE 37-103, 37-149
310	-	RWMA Class 3	-
C18000	C18000	RWMA Class 3	-
C95510	C95510	AMS 4880	-
ToughMet® 3	C72900	AMS 4598 AIMS 02-04-002 ABS 5152 MTL 4112	-
	C96900	ASTM B 505	-

ASTM	American Society for Testing and Materials
SAE	Society of Automotive Engineers
AMS	Aerospace Materials Specification (published by SAE)
EN	Comité Européen de Normalisation (Europe)
JIS	Japanese Industrial Standard (Japan)
GB	Standardization Administration of China
BMS	Boeing Material Specification
AIMS	Airbus Industries Material Specification
RWMA	Resistance Welders Manufacturer's Association
QQ	US Federal Specification
ISO	International Standards Organization
DIN	Deutsches Institut fur Normung (Germany)
BS	British Standard (UK)
NF	Association Française de Normalisation (France)
UNE	Instituto Español de Normalización (Spain)

NOTE: 1) Unless otherwise specified, material will be produced to ASTM specifications. 2) Withdrawn and superseded specifications are listed for reference only, since they may appear on older drawings. They are not to be used for purchasing. Contact your local Materion Brush Performance Alloys sales representative to determine the appropriate replacement specification.

Mechanical and Electrical Properties of Tube Products

Alloy	Temper[1]	Heat Treatment Specification	Outer Diameter	Wall Thickness	Tensile Strength	Yield Strength 0.2% Offset	Elongation	Rockwell Hardness	Electrical Conductivity
			in	in	ksi	ksi	Percent	B or C Scale	Percent IACS
			mm	mm	MPa	MPa			
25 C17200	A (TB00)	3 - 4 hr 600 - 675 °F	0.75 to 16	Note 3	60 - 85	20 - 35	20 - 75	B45 - 85	15 - 20
		3 - 4 hr 315 - 357 °C	19.1 to 406		410 - 590	130 - 250			
	H (TD04)	2 - 3 hr 600 - 675 °F	Up to 3/8	Note 3	90 - 130	75 - 105	8 - 30	B88 - 103	15 - 20
		2 - 3 hr 315 - 357 °C	Up to 9.5		620 - 900	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 3/8 to 1	Note 3	90 - 125	75 - 105	8 - 30	B88 - 102	15 - 20
		2 - 3 hr 315 - 357 °C	Over 9.5 to 25.4		620 - 860	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 1 to 3	Note 3	85 - 120	75 - 105	8 - 20	B88 - 101	15 - 20
		2 - 3 hr 315 - 357 °C	Over 25.4 to 76		590 - 830	520 - 720			
	AT (TF00)	-	0.75 to 16	Note 3	165 - 200	145 - 175	4 - 10	C36 - 42	25 - 30
			19.1 to 406		1140 - 1380	1000 - 1210			
			3 to 16	Note 3	165 - 200	130 - 175	3 - 10	C36 - 42	25 - 30
			76 to 406		1140 - 1380	900 - 1210			
	HT (TH04)	-	Up to 3/8	Note 3	185 - 225	160 - 200	2 - 9	C39 - 45	25 - 30
			Up to 9.5		1280 - 1550	1103 - 1380			
			Over 3/8 to 1	Note 3	180 - 220	155 - 195	2 - 9	C38 - 44	25 - 30
			Over 9.5 to 25.4		1240 - 1520	1070 - 1340			
			Over 1 to 3	Note 3	175 - 215	145 - 190	4 - 9	C37 - 44	25 - 30
			Over 25.4 to 76		1210 - 1480	1000 - 1310			
165 C17000	A (TB00)	3 - 4 hr 600 - 675 °F	0.75 to 16	Note 3	60 - 85	20 - 35	20 - 60	B45 - 85	15 - 20
		3 - 4 hr 315 - 357 °C	19.1 to 406		410 - 590	130 - 250			
	HT (TH04)	2 - 3 hr 600 - 675 °F	Up to 3/8	Note 3	90 - 130	75 - 105	8 - 30	B92 - 103	15 - 20
		2 - 3 hr 315 - 357 °C	Up to 9.5		620 - 900	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 3/8 to 1	Note 3	90 - 125	75 - 105	8 - 30	B91 - 102	15 - 20
		2 - 3 hr 315 - 357 °C	Over 9.5 to 25.4		620 - 860	520 - 720			
		2 - 3 hr 600 - 675 °F	Over 1 to 3	Note 3	85 - 120	75 - 105	8 - 20	B88 - 101	15 - 20
		2 - 3 hr 315 - 357 °C	Over 25.4 to 76		590 - 830	520 - 720			
	AT (TF00)	-	0.75 to 3	Note 3	150 - 190	125 - 155	4 - 10	C32 - 39	25 - 30
			19.1 to 76		1030 - 1310	860 - 1070			
			3 to 16	Note 3	150 - 190	125 - 155	3 - 10	C32 - 39	25 - 30
			76 to 406		1030 - 1310	860 - 1070			
	HT (TH04)	-	Up to 3/8	Note 3	170 - 210	145 - 185	2 - 5	C35 - 41	25 - 30
			Up to 9.5		1170 - 1450	1000 - 1280			
			Over 3/8 to 1	Note 3	170 - 210	145 - 185	2 - 5	C35 - 41	25 - 30
			Over 9.5 to 25.4		1170 - 1450	1000 - 1280			
			Over 1 to 3	Note 3	165 - 200	135 - 175	4 - 9	C34 - 39	25 - 30
			Over 25.4 to 76		1140 - 1380	930 - 1210			
3 C17510 and 10 C17500	A (TB00)	3 hr 850 - 900 °F	0.75 to 16	Note 3	35 - 55	10 - 30	20 - 35	B20 - 50	20 - 30
		3 hr 450 - 480 °C	19.1 to 406		240 - 380	70 - 210			
	H (TD04)	2 hr 850 - 900 °F	Up to 3	Note 3	65 - 80	50 - 75	10 - 15	B60 - 80	20 - 30
		2 hr 450 - 480 °C	Up to 76		450 - 550	350 - 520			
	AT (TF00)	-	0.75 to 16	Note 3	100 - 130	80 - 100	10 - 25	B92 - 100	45 - 60
			19.1 to 406		690 - 900	550 - 690			
	HT (TH04)	-	Up to 3	Note 3	110 - 140	95 - 125	5 - 25	B95 - 102	48 - 60
			Up to 76		760 - 970	660 - 860			
310	AT/HT[3]	-	0.75 to 16	Note 3	104 - 119	96 - 107	10 - 14	BHN 230 (B98) min.	45
			19.1 to 406		720 - 820	660 - 740			
C18000	AT/HT[2]	-	1 to 8	Note 3	90	70	14	B90 min.	45 min.
			25.4 to 203		620	480			
C95510	TQ50	-	2 - 4	Note 3	105 min.	62.5 min.	9 min.	-	-
			50.8 - 100		720 min.	430 min.			
		-	4 - 17	Note 3	95 min.	56 min.	9 min.	-	-
			100 - 432		660 min.	390 min.			
ToughMet®2 C96970	CX 90	-	Note 3	0.5 to 4	105 min.	90 min.	3 min.	C27 min.	13 - 14
				12.7 to 101.6	720 min.	620 min.			
ToughMet®3 C96900	CX 90	-	Note 3	0.5 to 4	105 min.	90 min.	6 min.	C27 min.	7 - 8
				12.7 to 101.6	720 min.	620 min.			
	CX 105	-	Note 3	0.5 to 4	110 min.	105 min.	4 min.	C30 min.	7 - 8
				12.7 to 101.6	760 min.	720 min.			

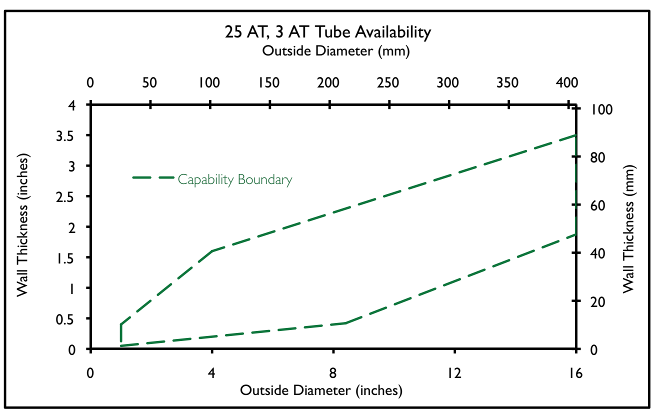
NOTE: 1) ASTM alphanumeric code for tempers. 2) Alloys 310 and C18000 are provided in either AT (TF00) or HT (TH04) temper depending on required size. Consult your sales engineer for precise availability. 3) Available wall thickness is approximately 10 to 25% of the outside diameter. Consult your local sales engineer for precise availability.

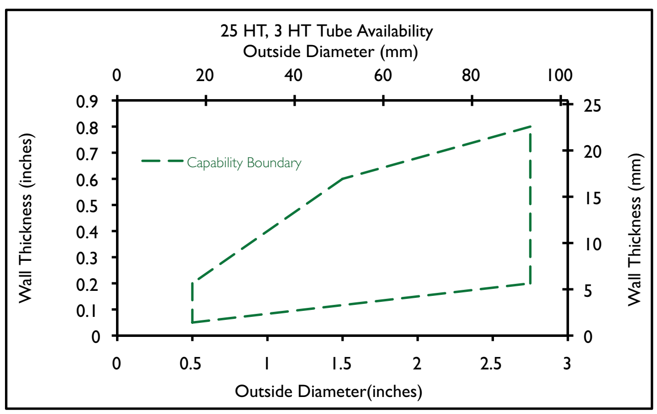
Mechanical and Electrical Properties of Tube Products

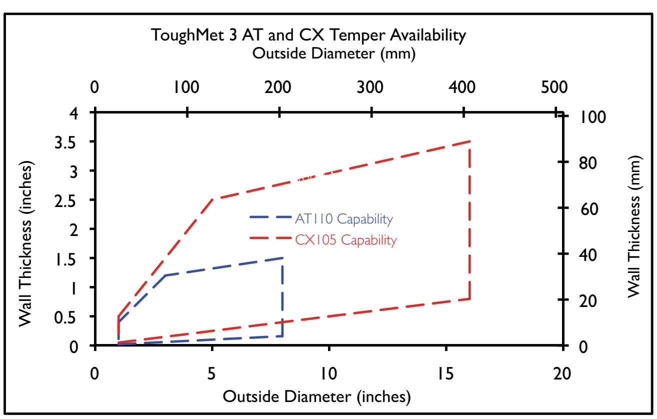
Alloy	Temper[1]	Heat Required	Outer Diameter	Wall Thickness	Tensile Strength	Yield Strength 0.2% Offset	Elongation	Rockwell Hardness	Electrical Conductivity
			in	in	ksi	ksi	Percent	B or C Scale	Percent IACS
			mm	mm	MPa	MPa			
ToughMet® 3 C72900	AT 90 (TX00)	-	1.625 to 4	0.25 min[3]	110 min.	90 min.	15 min.	C22 min.	7 - 8
			41 to 102	6.4 min[3]	760 min.	620 min.			
			Over 4 to 6.5	0.25 min[3]	110 min.	90 min.	12 min.	C22 min.	7 - 8
			102 to 165	6.4 min[3]	760 min.	620 min.			
			Over 6.5 to 8	0.25 min[3]	110 min.	90 min.	12 min.	C22 min.	7 - 8
			165 to 203	6.4 min[3]	760 min.	620 min.			
	AT 110 (TX00)	-	1.625 to 4	0.25 min[3]	130 min.	110 min.	10 min.	C30 min.	7 - 8
			41 to 102	6.4 min[3]	860 min.	760 min.			
			Over 4 to 6.5	0.25 min[3]	125 min.	110 min.	6 min.	C30 min.	7 - 8
			102 to 165	6.4 min[3]	860 min.	760 min.			
			Over 6.5 to 8	0.25 min[3]	125 min.	110 min.	6 min.	C30 min.	7 - 8
			165 to 203	6.4 min[3]	860 min.	760 min.			
			8.1 to 13	3 max[3]	128 min.	110 min.	5 min.	C30 min.	7 - 8
			206 to 330	75 max[3]	880 min.	760 min.			
ToughMet® 3 C72900	TS 150 (TXTS)	-	1.67 - 2.25	Note 3	158 min.	150 min.	5 min.	C36 min.	< 7
			42 - 57		1089 min.	1034 min.			

NOTE: 1) ASTM alphanumeric code for tempers. 2) Alloys 310 and C18000 are provided in either AT (TF00) or HT (TH04) temper depending on required size. Consult your sales engineer for precise availability. 3) Available wall thickness is approximately 10 to 25% of the outside diameter. Consult your local sales engineer for precise availability.

Available Tube Sizes







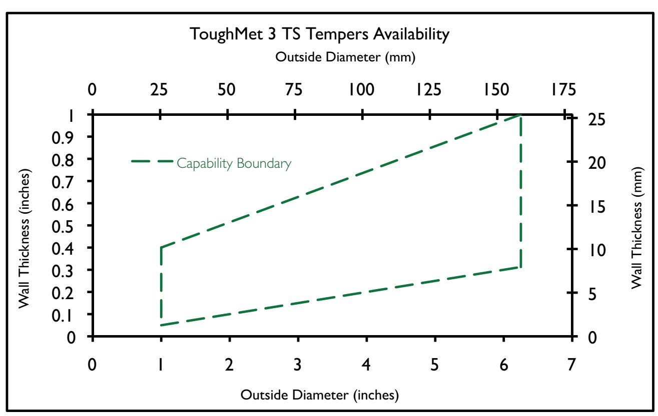


Plate and Rolled Bar

Plate and rolled bar are made with exacting attention to detail. Plate is a straight length of flat rolled product thicker than 0.188 inches (4.8 mm) and in widths from 12 to 24 inches (305 mm to 559 mm). Rolled bar is a rectangular or square section that is abrasively cut or sawed from plate. Plate is available in lengths ranging from 24 to 126 inches (610 to 3200 mm). Larger sizes may be available from alternative processes, please consult with the mill for details.

The copper beryllium alloys, with the exception of Alloy 310, are available in solution annealed (A), cold rolled (H) and age hardened tempers (AT and HT). Temper selection depends on the application and the method of component fabrication. For example, with Alloy 25 the annealed temper is the preferred selection when small holes are to be drilled; age hardening to the desired hardness is performed after drilling. Heat treated alloys are selected when heavier cuts using more rigid tooling can be made.

If the "A" or "H" temper is selected, parts are usually machined oversize to accommodate the slight dimensional change that occurs during hardening. The parts are then finish machined.

Plate Tolerance

(inches)

Plate Thickness		Brush Standard Thickness Tolerance
Over	Including	(plus or minus)
0.188	0.205	0.020
0.205	0.300	0.024
0.300	0.500	0.030
0.500	0.750	0.038
0.750	1.00	0.046
1.00	1.50	0.056
1.50	3.00	0.066
3.00	-	0.125

(mm)

Plate Thickness		Brush Standard Thickness Tolerance
Over	Including	(plus or minus)
5.0	8.0	0.60
8.0	13.0	0.80
13.0	20.0	1.00
20.0	30.0	1.20
30.0	40.0	1.40
40.0	60.0	1.70
60.0	-	3.175

NOTE: Tolerances are for widths up to 24 inches (610 mm). Specific width tolerance is plus 0.25/minus 0.00 inches (plus 6.35/minus 0.00 mm). Additional tolerances per ASTM B 248. Please specify your required tolerance when you order. Tighter tolerances may be available at additional cost. Please contact your sales engineer to confirm the requested capability.

The other alloys only are available in the fully heat treated condition, in single tempers. The MoldMAX® alloys are tabulated separately on page 31 in the plastic tooling alloy section.

These flat rolled products are noted for dimensional stability both in precision machining and in service. Thermal management devices of various types are common applications. Thermal conductivity, fatigue resistance and excellent machinability are key features contributing to cost effective use.

Examples of plate and rolled bar applications are:

- Heat conductive molds for plastic injection systems
- Structural components in electrical resistance welding
- Galling resistant wear plates and rub strips
- Metal die casting, plastic blow molding and injection molding inserts
- Damage resistant, non-sparking tools

Plate Specifications[1]

Brush Alloy	UNS Number	Current	Withdrawn/ Superseded[2]
25	C17200	ASTM B 194 SAE J 461, 463 AMS 4530, 4533, 4534 AMS 4650, 4651 RWMA Class 4 JIS H 3130	QQ-C-530 DIN 17670, 17672 NFL 14721, 147091
165	C17000	ASTM B 194 SAE J 461, 463 RWMA Class 4 JIS H 3130	DIN 17670
3	C17510	ASTM B 534 SAE J 461, 463 RWMA Class 3	DIN 17670, 17672
10	C17500	ASTM B 534 SAE J 461, 463 RWMA Class 3	DIN 17670, 17672
310	-	EN 1652 RWMA Class 3	-
ToughMet® 3	C72900	AMS 4595	-
C18000	C18000	RWMA Class 3	-

ASTM	American Society for Testing and Materials
SAE	Society of Automotive Engineers
AMS	Aerospace Materials Specification (published by SAE)
JIS	Japanese Industrial Standard (Japan)
RWMA	Resistance Welders Manufacturer's Association
QQ	US Federal Specification
DIN	Deutsches Institut fur Normung (Germany)
NF	Association Française de Normalisation (France)

NOTE: 1) Unless otherwise specified, material will be produced to ASTM specifications. 2) Withdrawn and superseded specifications are listed for reference only, since they may appear on older drawings. They are not to be used for purchasing. Contact your local Materion Brush Performance Alloys sales representative to determine the appropriate replacement specification.

Mechanical and Electrical Properties of Plate and Rolled Bar Products

Alloy	Temper[1]	Heat Treatment Specification	Thickness	Tensile Strength	Yield Strength 0.2% Offset	Elongation	Rockwell Hardness	Electrical Conductivity
			in	ksi	ksi	Percent	B or C Scale	Percent IACS
			mm	MPa	MPa			
25 C17200	A (TB00)	3 hr 600-675 °F	0.5 to 8	60 - 85	20 - 35	20 - 75	B45 - 85	15 - 20
		3 hr 316-357 °C	12.7 to 203.2	410 - 590	130 - 250			
	H (TD04)	2 hr 600-675 °F	0.188 to 3/8	90 - 130	75 - 105	8 - 20	B91 - 103	15 - 20
		2 hr 316-357 °C	4.78 to 9.5	620 - 900	520 - 720			
		2 hr 600-675 °F	Over 3/8 to 1	90 - 125	75 - 105	8 - 20	B90 - 102	15 - 20
		2 hr 316-357 °C	Over 9.5 to 25.4	620 - 860	520 - 720			
		2 hr 600-675 °F	Over 1 to 2	85 - 120	75 - 105	8 - 20	B88 - 102	15 - 20
		2 hr 316-357 °C	Over 25.4 to 51	590 - 830	520 - 720			
		2 hr 600-675 °F	Over 2 to 3	85 - 120	75 - 105	8 - 20	B88 - 102	15 - 20
		2 hr 316-357 °C	Over 51 to 76	590 - 830	520 - 720			
	AT (TF00)	-	0.5 to 8	165 - 200	140 - 175	3 - 10	C36 - 41	25 - 30
			12.7 to 203.2	1140 - 1380	970 - 1200			
	HT (TH04)	-	0.188 to 3/8	180 - 215	160 - 200	1 - 5	C38 - 45	25 - 30
			4.78 to 9.5	1240 - 1490	1100 - 1380			
			Over 3/8 to 1	180 - 220	155 - 200	1 - 5	C38 - 44	25 - 30
			Over 9.5 to 25.4	1240 - 1520	1060 - 1380			
			Over 1 to 2	175 - 215	150 - 200	2 - 5	C37 - 43	25 - 30
			Over 25.4 to 51	1200 - 1490	1030 - 1380			
			Over 2 to 3	165 - 200	130 - 180	2 - 5	C36 - 42	25 - 30
			Over 51 to 76	1140 - 1380	890 - 1250			
165 C17000	A (TB00)	3 hr 600-675 °F	0.5 to 8	60 - 85	20 - 35	20 - 60	B45 - 85	15 - 20
		3 hr 316-357 °C	12.7 to 203.2	410 - 590	130 - 250			
	HT (TH04)	2 hr 600-675 °F	0.188 to 3/8	90 - 130	75 - 105	8 - 20	B92 - 103	15 - 20
		2 hr 316-357 °C	4.78 to 9.5	620 - 900	520 - 720			
		2 hr 600-675 °F	Over 3/8 to 1	90 - 125	75 - 105	8 - 20	B91 - 102	15 - 20
		2 hr 316-357 °C	Over 9.5 to 25.4	620 - 860	520 - 720			
		2 hr 600-675 °F	Over 1 to 2	85 - 120	75 - 105	8 - 20	B88 - 101	15 - 20
		2 hr 316-357 °C	Over 25.4 to 51	590 - 830	520 - 720			
		2 hr 600-675 °F	Over 2 to 3	85 - 120	75 - 105	8 - 20	B88 - 101	15 - 20
		2 hr 316-357 °C	Over 51 to 76	590 - 830	520 - 720			
	AT (TF00)	-	0.5 to 8	150 - 190	130 - 155	3 - 10	C33 - 39	25 - 30
			12.7 to 203.2	1030 - 1310	890 - 1070			
	HT (TH04)	-	0.188 to 3/8	170 - 210	135 - 165	2 - 5	C35 - 41	25 - 30
			4.78 to 9.5	1170 - 1450	930 - 1140			
			Over 3/8 to 1	170 - 210	135 - 165	2 - 5	C35 - 41	25 - 30
			Over 9.5 to 25.4	1170 - 1450	930 - 1140			
			Over 1 to 2	165 - 200	135 - 165	2 - 5	C34 - 39	25 - 30
			Over 25.4 to 51	1140 - 1380	930 - 1140			
			Over 2 to 3	160 - 190	125 - 165	2 - 5	C34 - 38	25 - 30
			Over 51 to 76	1100 - 1310	860 - 1140			
3 C17510 and 10 C17500	A (TB00)	3 hr 850-900 °F	1.75 to 5	35 - 55	25 - 45	20 - 35	B 20 - 45	20 - 30
		3 hr 454-482 °C	44.5 to 127	240 - 380	170 - 310			
	H (TD04)	2 hr 850-900 °F	0.188 to 3	70 - 85	55 - 80	2 - 8	B78 - 88	20 - 30
		2 hr 454-482 °C	4.78 to 76	480 - 590	380 - 550			
	AT (TF00)	-	1.75 to 5	100 - 130	80 - 100	8 - 20	B92 - 100	45 - 60
			44.5 to 127	690 - 900	550 - 690			
	HT (TH04)	-	0.188 to 3	110 - 140	100 - 120	5 - 15	B95 - 102	48 - 60
			4.78 to 76	760 - 970	690 - 830			
310	(Note 2)	-	(Note 2)	104 - 119	96 - 107	10 - 14	B98 min.[3]	45
			-	720 - 820	660 - 740			
ToughMet® 2 C96970	CX 90	-	2 to 12	105 min.	90 min.	3 min.	C27 min.	13 - 14
			50.8 to 304.8	720 min.	620 min.			
ToughMet® 3 C72900	AT 110	-	0.15 to 4.5	125 min.	110 min.	5 min.	C30 min.	7 - 8
			3.8 to 114.3	860 min.	760 min.			
C18000	TF00	-	0.5 to 8	90 nom	70 nom	14 nom	B90 min.	45 min.
			12.7 - 203.2	620 nom	480 nom			
FormaMet®	-	-	1.5 to 7.0	-	-	<0.5%	C39	6
			38.1 to 177.8	-	-			

NOTE: 1) ASTM alphanumeric code for tempers. 2) Alloy 310 temper either AT (TF00) or HT (TH04) depending on size and shape. 3) Alloy 310 minimum HRB 98 hardness is a direct conversion from 230 HBS (Brinell test with a steel indenter).

MoldMAX® and PROtherm™ Plastic Tooling Alloys

Materion Brush Performance Alloys offers a variety of mold alloys to fit your every need. Copper beryllium alloys include MoldMAX HH® (High Hardness), MoldMAX LH® (Low Hardness) and PROtherm™, formerly known as MoldMAX SC®. Materion Brush Performance Alloys also offers non-beryllium alloys in MoldMAX XL®, MoldMAX V® and C18000.

All MoldMAX® and PROtherm™ products are high performance alloys specifically designed for the plastic processing industry. These alloys offer a unique combination of thermal conductivity and strength that provides important benefits for the molding process.

Through the unique combination of thermal conductivity and strength available in the MoldMAX® product line, these copper mold alloys provide:

- Shorter cycle time
- Improved plastic part dimensional accuracy
- Better parting line maintenance
- Excellent corrosion resistance

MoldMAX® provides strength and wear resistance similar to that of many tool steels. In addition, MoldMAX® offers a thermal conductivity up to ten times greater than steel. MoldMAX® is typically specified for:

- Injection mold components and core/cavity inserts
- Hot runner system injection nozzles and manifolds
- Blow mold pinch offs, neck rings and handle inserts

PROtherm™ provides the highest thermal conductivity available in a mold material…ten times greater than steel and twice that of aluminum. PROtherm™ also offers a hardness and strength exceeding aluminum. PROtherm™ is specifically designed for foam processing, hot runner systems, blow molds and other applications where maximum heat removal or control is required.

MoldMAX® and PROtherm™ attributes:

- Heat treated and ready to machine
- Resistant to corrosion
- Fully machinable
- Easy to polish
- Can be welded to copper and other alloys
- Available in large block sizes
- High levels of strength and conductivity

For more than 20 years, Brush Performance Alloys has been committed to bringing high thermal conductivity and uniform cooling into the plastics market. Today, as part of our service we bring infrared (IR) imaging technology to you. With sophisticated IR cameras and knowledgeable staff we can look at your molded part and show you, in real time, how and where the thermal management properties of MoldMAX® or PROtherm™ can make a difference in your part and your molding operations.

Seeing is believing, which is why Brush Performance Alloys has invested in IR technology worldwide. We are just as committed to helping our customers better manage the thermal properties of their molds today as we were more than 20 years ago.

Mechanical and Thermal Properties of MoldMax® and PROtherm™ Products

Alloy	Tensile Strength	Yield Strength 0.2% Offset	Charpy V-Notch Impact Strength	Thermal Conductivity at 100°C (212°F)	Thermal Expansion Coefficient	R=-1 Fatigue Strength 10^7 Cycles	Elongation	Rockwell Hardness
	ksi	ksi	ft-lbs	BTU/ft·hr·°F	10^{-6} in/in·°F	ksi	Percent	C Scale
	MPa	MPa	J	W/m·°C	10^{-6} m/m·°C	MPa		
MoldMAX HH®	170	145	4	75	9.7	45 min.	5	C40
	1175	1000	5	130	17.5	310 min.		
MoldMAX LH®	140	110	12	90	9.7	45 min.	15	C30
	965	760	16	155	17.5	310 min.		
MoldMAX XL®	115	105	10	40	9.3	35 nom	6	C28
	795	725	13	70	16.7	240 nom		
MoldMAX V®	115	100	4	92	9.7	35 nom	7	C28[2]
	790	690	5	160	17.5	240 nom		
PROtherm™[1]	105	90	40	145	9.8	40 nom	15	C20
	725	620	54	250	17.6	275 nom		
C18000	90	70	35	135	9.7	-	14	C16
	620	480	48	235	17.5	-		

NOTE: 1) PROtherm™ was formerly known as MoldMAX SC®. 2) Hardness of rod = 270 HBS minimum. Hardness of plate ≤ 4.5 in (114 mm) thickness = 250 HBS minimum. Hardness of plate > 4.5 in (114 mm) thickness = 220 HBS minimum.

ToughMet® and Alloy 25 Oilfield Products

ToughMet® 3 and copper beryllium **Alloy 25** both comply with NACE MR0175 and ISO 15156 panels for unrestricted Sour Well Service with no restriction on hardness (tested up to 150 °C NACE Level V). These alloys resist galling when in contact with stainless steels and other high nickel alloys, and possess sufficient resistance to wear and erosion for oilfield applications. Both alloys have an elastic modulus approximately 33% lower than steel, resulting in high bending resilience. Both are non-magnetic with a relative permeability < 1.001. These alloys provide high strength and strain tolerance (fatigue life). They have very good machinability compared to other materials, particularly steel and nickel alloys. They also can be a substantial cost saving material when compared to nickel alloys.

NACE standard testing indicates no susceptibility to chloride (brine / seawater / completion fluid) cracking or pitting corrosion in these alloys, and they are immune to hydrogen embrittlement cracking (including notched areas) in sour wells. They also are not subject to biofouling. ToughMet® 3 shows resistance to amine-based fluid corrosion (no embrittlement or accelerated weight loss). ToughMet® 3 is resistant to sulfide stress cracking when at partial pressures of H_2S shown below.

Corrosion Rate of ToughMet® 3 in Simulated Oilfield Environments in inches per year (mm per year)

Alloy	Temper	Hardness HRC nom.	NACE Environment				
			Level I	Level II	Level IV	Level V	Level VII
ToughMet®3	CX	30	<0.5 (<13)	0.7 (18)	1.3 (33)	6.9 (175)	-
ToughMet®3	TX(AT)	30	<0.5 (<13)	0.8 (20)	1.3 (33)	3.7 (94)	-
ToughMet®3	TS	70	<0.5 (<13)	1.1 (28)	4.0 (100)	Cracking	Cracking

Definition of Environment

	NACE Environment				
	Level I	Level II	Level IV	Level V	Level VII
Temperature °F (°C)	73 (23)	73 (23)	194 (90)	302 (150)	401 (205)
H_2S Partial Pressure in psi (MPa)	0	Saturated	0.43 (0.003)	101 (0.7)	508 (3.5)
CO_2 Partial Pressure in psi (MPa)	0	-	101 (0.7)	203 (1.4)	508 (3.5)
Acetic Acid (%)	0	0.5	-	-	-
NaCl (%)	5	5	15	15	25

NOTE: No cracking in 720 hours of service, unless otherwise specified.

Alloy 25 Drill String Temper (25 DST)

A special temper of copper beryllium has been developed to meet the specific needs of oil and gas well drilling. Components for this demanding environment serve as part of the drill string's bottom hole assembly and enclose sensitive magnetic measuring instrumentation. These tubular components must be transparent to magnetic fields, must resist corrosion, must be strong enough to withstand the stress of tightly torqued threaded connections, and tough enough to withstand the rotating and bending abuse of downhole service.

Brush Alloy 25 Drill String Temper meets these requirements. In addition, it is noted for its ability to minimize galling in threaded tool joints. The "thread saver sub" for example, eliminates galled threads in the drill string bottom hole assembly and prolongs the life of adjoining components.

Drill String Temper is not susceptible to chloride stress corrosion cracking as the table on this page shows. It resists carbon dioxide and it is effectively immune to hydrogen embrittlement. In sour environments it is used for drilling and well logging where exposure is intermittent and inhibitors are used.

Brush Alloy 25 has low magnetic permeability (between 0.997 and 1.003) that does not change under severe service or handling, is easily machined and resists thread damage without the need for special coatings or treatments.

Resistance to Chloride Stress Corrosion Cracking

Temperature	300°F 150°C	311°F 155°C	300°F 150°C
Applied Stress (percent of 0.2% offset yield strength)	100	100	100
Oxygen Content (parts per million in saturating gas)	1*	1	5000*
pH	8	3	7
Chloride Concentration (weight percent)			
sodium (Na)	3	0	0
potassium (K)	10	0	6
magnesium (Mg)	0	42	25
Test Duration (hours)	720	1000	1000
Test Result	No Cracking	No Cracking	No Cracking

NOTE: * Total pressure 1000 psi.

Brush Alloy 25 meets all requirements of American Petroleum Institute Spec 7 for drill collars and rotary substitutes. Mechanical properties and results of performance tests are in the accompanying tables.

Examples of drill string applications are:

- Nonmagnetic drill collars
- Measurement while drilling components
- Instrument housings
- Threaded saver subs
- Drill rod for coring tools in mining or hydrocarbon drilling and exploration
- Mud motor flexible drive shafts
- Cross over subs

Mechanical Properties for Copper Beryllium Drill String Subs and Collars

Drill Collar Outside Diameter	Minimum Tensile Strength	Minimum Yield Strength 0.2% Offset	Minimum Elongation
inches	ksi	ksi	Percent
mm	MPa	MPa	
up to 7	140	110	12
up to 189	970	760	
7 - 11	135	100	13
180 - 280	930	690	
over 11	120	90	13
over 280	830	620	

NOTE: Tensile tests per ASTM E 8.

Resistance to Galling in Threaded Joint

Couple (pin/box)	Onset of Galling Failure (percent of API Minimum Torque) Lubricated	Non-lubricated
Stainless/Stainless [1]	130	< 100
Alloy 25/Stainless [2]	NF at 180	-
Alloy 25/Stainless [1]	NF at 200	200
Alloy 25/AISI 4140 [2]	NF at 205	-
Alloy 25/Alloy 25 [1]	NF at 200	NF at 200

NOTE: 1) API NC-38 2) API 6-5/8 REG
NF=No Failure.

BrushCAST® Casting Ingot & Master Alloys

BrushCAST® Ingot

Copper beryllium casting ingot is available in high conductivity and high strength compositions for casting without additions. Investment, shell, permanent mold, sand, centrifugal and pressure casting are a few of the methods used. Beryllium in copper increases melt fluidity and cleanliness while providing a heat treatable casting. Replication of mold detail in cast parts is excellent.

BrushCAST® High Strength Casting Alloys **275C, 165C, 21C and 20C** provide peak strength and hardness greater than many steels, but with thermal conductivity similar to that of aluminum and up to five times that of steel. Additionally, these alloys offer good electrical conductivity, excellent wear and galling resistance and the highest accuracy in replicating fine detail in cast components.

BrushCAST® High Conductivity Casting Alloy **3C** offers excellent electrical and thermal conductivity, good strength and galling resistance and accurate replication of component detail. Alloy 3C offers nearly three times the conductivity of the high strength alloys, twice the thermal conductivity of aluminum alloys and ten times that of steel.

BrushCAST® high strength casting alloys are available in fine grain equivalents including: Alloys **20CT, 275CT, and 165CT. Alloy 21C** is naturally fine grained.

Material properties and manufacturing characteristics are similar to those of the standard casting alloys. Grain refinement is achieved through precise additions of either cobalt or titanium. Our fine grain casting alloys are preferred in applications where excellent surface finish characteristics are required in the cast product.

BrushCAST® alloys are available in precise measurement, easy to use shot. BrushCAST® master alloy and cast billet also are available.

Master Alloys

Common master alloys include 4% beryllium copper, 5% beryllium aluminum, and 6% beryllium nickel. Supplied as ingot or shot, master alloy is a melt additive used for one or more of the following purposes: to harden copper, nickel and aluminum; to improve cleanliness, fluidity and corrosion resistance in aluminum; to minimize loss of oxidizable elements such as magnesium in aluminum; to protect against oxidation and melt ignition in magnesium; and to control composition in production of commercial beryllium-containing alloys in many base metal systems.

Processing Temperatures for BrushCAST® Casting Alloys

Alloy	Solidus	Liquidus	Pouring Range	Solution Annealing[1]	Age Hardening[2]
	°F	°F	°F	°F	°F
	°C	°C	°C	°C	°C
3C	1900	1970	2000 - 2150	1600 - 1650	900
	1000	1080	1090 - 1180	870 - 900	480
165C, 165 CT	1625	1810	1850 - 2050	1400 - 1450	650
	885	990	1010 - 1120	760 - 790	340
20C, 20 CT	1600	1780	1850 - 2050	1400 - 1450	650
	870	970	1010 - 1120	760 - 790	340
21C	1550	1760	1850 - 2050	1400 - 1450	650
	840	960	1010 - 1120	760 - 790	340
275C, 275CT	1570	1710	1760 - 1900	1400 - 1450	650
	850	930	960 - 1040	760 - 790	340

NOTE: 1) Annealing time is determined by section thickness. One hour per inch of thickness is recommended. A minimum of 3 hours at temperature is required for high strength alloys for the most uniform properties. Parts must be quenched in water or oil following solution anneal, although large parts should be air cooled or delayed in quenching to prevent cracking. 2) For the recommended age hardening temperatures, use a 3 hour hold time at temperature.

Chemical Composition of BrushCAST® Casting Alloys (weight percent)

Alloy	UNS Number	Beryllium (Be)	Cobalt (Co)	Nickel (Ni)	Silicon (Si)	Copper (Cu)
3C	C82200	0.35 - 0.80	-	1.0 - 2.0	-	Balance
165C, 165 CT	C82400	1.60 - 1.85	0.20 - 0.65	-	-	Balance
20C, 20 CT	C82500	1.90 - 2.25	0.35 - 0.70	-	0.20 - 0.35	Balance
21C	C82510	1.90 - 2.15	1.00 - 1.20	-	0.20 - 0.35	Balance
275C, 275CT	C82800	2.50 - 2.85	0.35 - 0.70	-	0.20 - 0.35	Balance

Physical Properties of BrushCAST® Casting Alloys

Alloy	UNS Number	Density	Elastic Modulus	Thermal Expansion Coefficient at 70 - 400 °F (20 - 200 °C)	Thermal Conductivity at 20 °C (70 °F)	Electrical Conductivity
		lbs/in³	10^6 psi	10^{-6} in/in -°F	BTU/ft hr -°F	Percent
		g/cm³	GPa	10^{-6} m/m -°C	W/m -°C	IACS
3C	C82200	0.319	20	10	144	45 - 50
		8.83	140	18	250	
165C, 165CT	C82400	0.304	19	10	58	20 - 25
		8.41	130	18	100	
20C, 20CT	C82500	0.300	19	10	56	18 - 25
		8.30	130	18	97	
21C	C82510	0.300	19	10	56	18 - 25
		8.30	130	18	97	
275C, 275CT	C82800	0.294	19	10	52	17 - 23
		8.14	130	18	90	

NOTE: Physical properties are measured after solution annealing and peak age hardening.

Mechanical Properties of BrushCAST® Casting Alloys

Alloy	Temper	Tensile Strength		0.2% Offset Yield Strength		Elongation	Rockwell Hardness
		ksi	MPa	ksi	MPa	Percent	B or C
3C	As Cast (M)	55 - 60	380 - 410	25 - 35	170 - 240	15 - 25	B55 - 65
	As Cast & Aged (O11)	60 - 75	410 - 520	40 - 55	280 - 380	10 - 20	B75 - 90
	Solution Annealed & Aged (TF00)	90 - 100	620 - 690	70 -80	480 - 550	5 - 10	B92 - 100
165C, 165CT	As Cast (M)	70 - 75	655 - 720	35 - 40	240 - 280	20 - 25	B74 - 82
	As Cast & Aged (O11)	95 - 105	450 - 520	65 - 75	450 - 520	10 - 20	C20 - 24
	Solution Annealed & Aged (TF00)	145 - 155	1000 - 1070	135 - 145	930 - 1000	2 - 4	C34 - 39
20C, 20CT, 21C	As Cast (M)	75 - 85	520 - 590	40 - 50	280 - 345	15 - 30	B80 - 85
	As Cast & Aged (O11)	100 - 105	690 - 720	70 - 75	480 - 520	10 - 20	C20 - 24
	Solution Annealed & Aged (TF00)	150 - 175	1030 - 1210	120 - 150	830 - 1030	1 - 3	C38 - 43
275C, C275 CT	As Cast (M)	85 - 90	590 - 620	50 - 60	345 - 410	5 - 25	B80 - 90
	As Cast & Aged (O11)	95 - 105	655 - 720	60 - 70	410 - 480	10 - 15	C20 - 25
	Solution Annealed & Aged (TF00)	180 - 195	1240 - 1340	165 - 180	1140 - 1240	0.5 - 3	C43 - 47

Forged and Extruded Finished Components

The ease with which copper alloys can be worked allows fabrication of large, near-net shape components by forging and extrusion.

Forging extends the size range available in copper beryllium components. Processes include rotary forging, ring rolling, roll forging, swaging, cold heading and various open and closed die techniques. Forgings include:

- Disc shaped resistance seam welding electrodes (open die forging)
- Generator rings (ring forged)
- Aerospace and hydrospace components
- Gears and power transmission couplings

Extrusions find application in continuous long lengths, where economy is achieved by near-net shape techniques; in short lengths where near-net shape processing is combined with high production rate; and in back extruded parts where relatively large diameter hollows can be produced economically. Extrusions include:

- Wear resistant guide rails for computer peripheral equipment
- Heat and fatigue resistant mold segments for continuous casting equipment
- Abrasion and galling resistant dies and die inserts for resistance flash welding
- Corrosion resistant, anti-galling cylinders for undersea cable communication system repeater housings

Forging and Extrusion Specifications[1]

Brush Alloy	UNS Number	Current	Withdrawn/ Superseded[2]
25	C17200	ASTM B 570 SAE J 461, 463 AMS 4650 RWMA Class 4 EN 12163, 12420	QQ-C-530 DIN 17670, 17672 NFL 14721, 147091
165	C17000	ASTM B 570 SAE J 461, 463 RWMA Class 4	-
3	C17510	ASTM B 938 RWMA Class 3 EN 12165, 12420	-
10	C17500	ASTM B 938 SAE J 461, 463 RWMA Class 3 EN 12165, 12420	BS 2872
310	-	RWMA Class 3	-
ToughMet® 3	C72900	-	-
C18000	C18000	RWMA Class 3	-

ASTM — American Society for Testing and Materials
SAE — Society of Automotive Engineers
AMS — Aerospace Materials Specification (published by SAE)
EN — Comité Européen de Normalisation (Europe)
RWMA — Resistance Welders Manufacturer's Association
QQ — US Federal Specification
BS — British Standard (UK)
UNI — Ente Nazionale Italiano di Unificazione (Italy)

NOTE: 1) Unless otherwise specified, material will be produced to ASTM specifications. 2) Withdrawn and superceded specifications are listed for reference only, since they may appear on older drawings. They are not to be used for purchasing. Contact your local Materion Brush Performance Alloys sales representative to determine the appropriate replacement specification.

Mechanical and Electrical Properties of Forgings and Extrusions

Alloy	Temper[1]	Heat Treatment Specification °F / °C	Tensile Strength ksi / MPa	Yield Strength 0.2% Offset ksi / MPa	Elongation Percent	Rockwell Hardness B or C Scale	Electrical Conductivity Percent IACS
25 C17200	A (TB00)	3 hr 625 °F	60 - 85	20 - 40	35 - 60	B45 - 85	15 - 19
		3 hr 330 °C	410 - 590	130 - 280			
	AT (TF00)	-	165 - 200	130 - 175	3 - 10	C36 - 42	22 - 28
		-	1140 - 1380	890 - 1200			
165 C17000	A (TB00)	3 hr 625 °F	60 - 85	20 - 40	35 - 60	B45 - 85	15 - 19
		3 hr 330 °C	410 - 590	130 - 280			
	AT (TF00)	-	150 - 190	120 - 155	3 - 10	C32 - 39	22 - 28
		-	1030 - 1310	830 - 1070			
3 C17510 and 10 C17500	A (TB00)	3 hr 900 °F	35 - 55	20 - 40	20 - 35	B20 - 50	20 - 35
		3 hr 480 °C	240 - 380	130 - 280			
	AT (TF00)	-	100 - 130	80 - 100	10 - 25	B92 - 100	45 - 60
		-	690 - 900	550 - 690			
310	AT (TF00)	-	104 - 119	96 - 107	10 - 14	B98 min.	45
		-	720 - 820	660 - 740			
ToughMet® 3 C96970	AT 110 (TX00)	-	120	110	5	C28	9
		-	930	760			

NOTE: 1) ASTM alphanumeric code for tempers. 2) Exact properties may vary depending upon wall thickness.

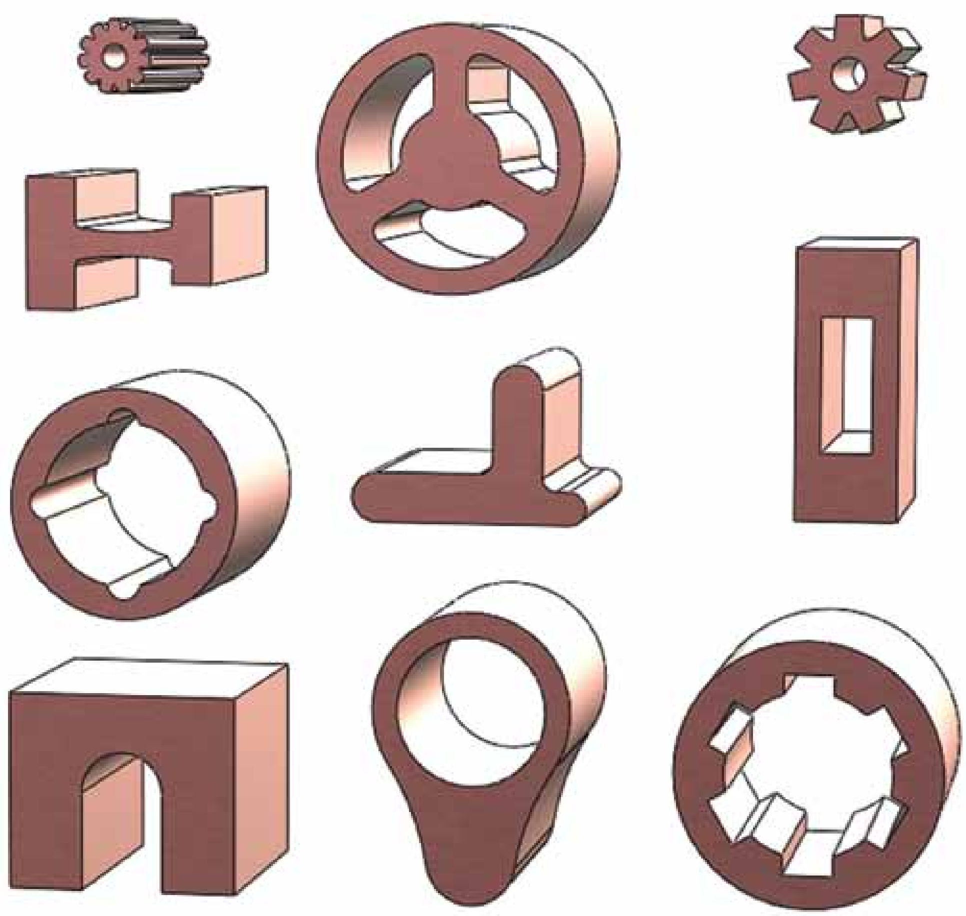
Cast Shapes

Materion Brush Performance Alloys' EquaCast® continuous casting process is a very cost-effective means of producing cast rod, bar and tubing in many non-beryllium containing copper alloys. This process also offers the additional advantage of casting near net shapes in a variety of configurations.

EquaCast® continuous cast shapes can dramatically lower the manufacturing costs of your components. Because the EquaCast® custom shape is much closer to the desired configuration of your component, it reduces both the input weight of the part prior to machining and the manufacturing time with the need for less metal removal.

Shown below are samples of some of the continuous cast shapes that can be produced. The limiting factor in designing a special shape is wall thickness. The process typically requires a minimum 0.500" (12.5 mm) wall thickness throughout the part.

Brush Performance Alloys currently provides a number of EquaCast® near net shapes to the oil and gas industry and other markets. Ask your Brush Performance Alloys sales engineer about how we can save you time and money with an EquaCast® continuous cast shape.



Recommended Replacements for Discontinued Alloys

As Materion Brush Performance Alloys continually develops new materials and alloys, older alloys will experience a decline in marketplace usage, and will be phased out and replaced. At other times, newer alloys do not become commercial successes, and production is discontinued after a limited time. Occasionally, a request may surface for a discontinued material, usually on an older print. For these reasons, Brush Performance Alloys publishes the following list of recommended replacements.

Alloy 165 (C17000) strip can be replaced by the corresponding temper of Alloy 25 or Alloy 190 strip (C17200). Each temper of Alloy 25 or 190 strip has better formability than its corresponding temper of Alloy 165.

Alloy 290 TM00 strip can be replaced by Alloy 190 AM. Both have identical formability and strength.

Alloy 10 (C17500) strip can be replaced directly with the corresponding temper of Alloy 3 (C17510). Alloy 3 was developed to be a drop-in substitute for Alloy 10, substituting nickel for cobalt in the chemistry. The mechanical and physical properties of Alloy 3 and Alloy 10 are identical.

Alloy 171 (C17450) strip can be replaced by Alloy 174 (C17410) strip in ½ HT temper. Alloy 174 has slightly higher strength at a penalty of slightly reduced formability.

BrushForm® 47 HT strip may be replaced by Alloy 390 HT

Alloy M65 (C17465) rod and wire can be replaced by Alloy M25 (C17300), Alloy 1916 (C19160) or by Brush 1915® (C19150). Use Alloy M25 or 1916 for parts that are machined, and Brush 1915® for parts that are cold-headed. The strength and conductivity of these alloys are the same as M65.

In rod form, **ToughMet® 3 TS110** can be replaced by ToughMet® 3 AT110 where friction and anti-galling properties are most important, or by ToughMet® 3 TS120U where ductility and impact strength are most important. In tube form, the TS110 temper can only be replaced by the AT110 temper.

You may wish to consider replacing **Nibryl** rod (N03360) with N05500 (Monel® K-500), or with N07718 (Inconel® 718). Both of these metals are produced by and are registered trademarks of Special Metals Corporation. If corrosion resistance is paramount, you may wish to consider Hastelloy® C-276 (produced by and a registered trademark of Haynes International) or MP35N® (produced by Carpenter Technology Corporation and a registered trademark of SPS Technologies).

Please contact Brush Performance Alloys for detailed comparisons of the properties of these discontinued alloys and their recommended replacements.

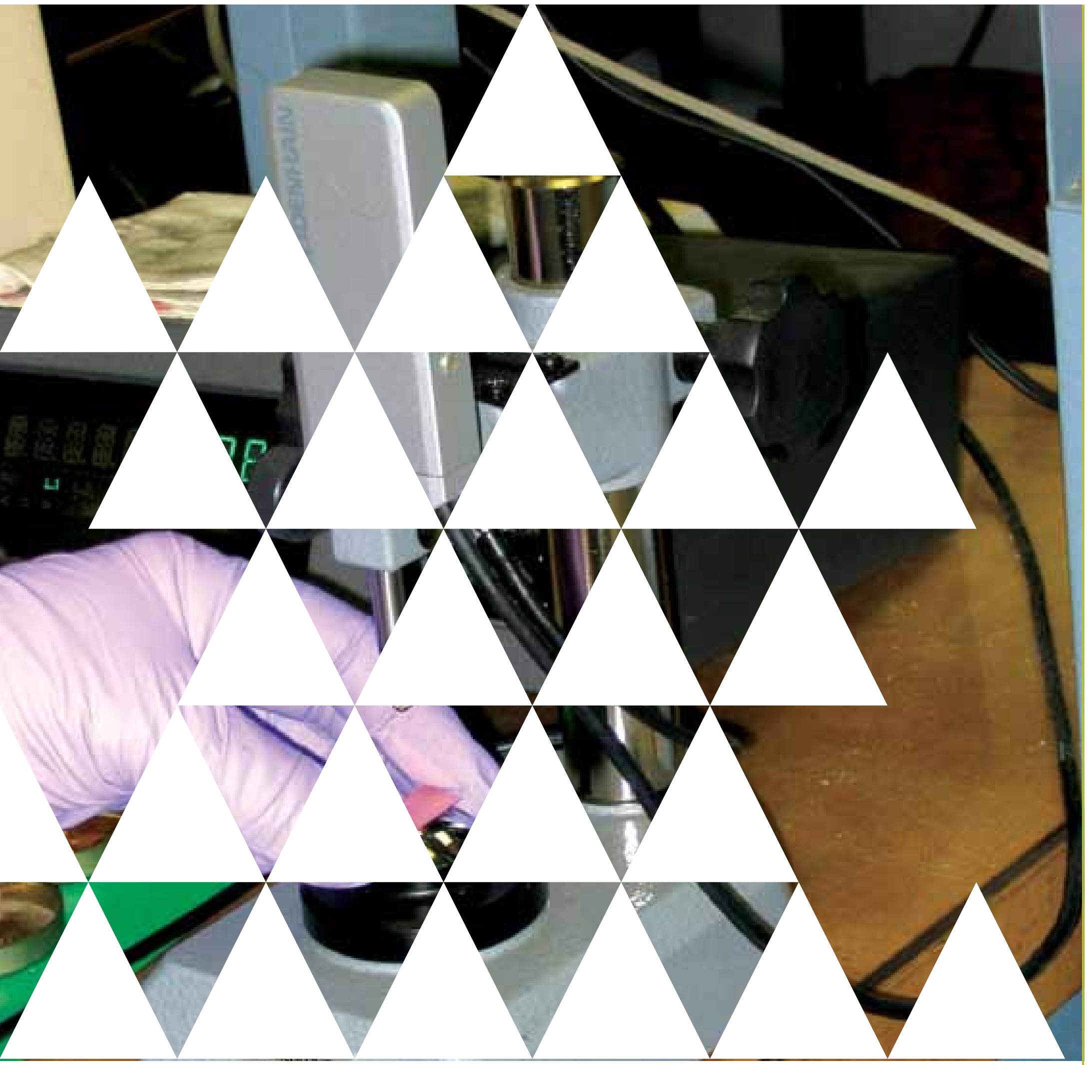
Strip Alloys

Discontinued Material		Suggested Replacement	
Alloy	Temper	Alloy	Temper
165	A	25	A
	1/4 H		1/4 H
	1/2 H		1/2 H
	H		H
	AT		AT
	1/4 HT		1/4 HT
	1/2 HT		1/2 HT
	HT		HT
165	AM	190	AM
	1/4 HM		1/4 HM
	1/2 HM		1/2 HM
	HM		HM
	SHM		SHM
	XHM		XHM
171	1/4 HT	174	1/2 HT
	1/2 HT		1/2 HT
50, 10	A	3	A
	H		H
	AT		AT
	HT		HT
BrushForm® 47	HT	390	HT
290	TM00	190	AM

Rod and Wire Alloys

Discontinued Material		Suggested Replacement	
Alloy	Temper	Alloy	Temper
M65	AT	M25, 1916, 1915	AT
M65	HT	M25, 1916, 1915	HT
ToughMet® 3	TS110	ToughMet® 3	AT110 or TS120U
Nibryl	A	Monel® K-500, Hastelloy® C276	H
Nibryl	H775	Monel® K-500, MP35N®	AT
Nibryl	H950	Inconel® 718, MP35N®	1/4 HT
Nibryl	H1050	Inconel® 718, MP35N®	1/2 HT
50	AT	3	AT
50	1/2 HT	3	HT
50	HT	3	HT

Materion Brush Performance Alloys Value-Added Service



As the world's leading supplier of high performance copper alloys, Materion Brush Performance Alloys offers customers more than just superior materials. Driven by our customers' complete satisfaction, Brush Performance Alloys is your partner for unmatched customer support.

Materion Brush Performance Alloys' strength lies in our team of exceptional technical, manufacturing and customer support members. We have assembled an impressively credentialed staff of experts in materials science, component design and manufacturing methodologies. From assistance with product design and development to innovative manufacturing practices as well as courteous and accommodating customer service, our team members work with customers to provide material solutions that best meet their individual needs.

Custom Fabrication Capabilities

Materion Brush Performance Alloys' manufacturing capability often provides an economical alternative to in-house fabrication of high performance alloy parts. Our custom fabrication department can assist you by fabricating finished or ready to finish parts from our materials or other materials.

After completing a producibility analysis of the customer's drawings and specifications, an experienced Materion Brush Performance Alloys' team can offer guidelines to producing a quality product cost effectively and on time. Our custom fabrication group also is willing to provide toll processing of materials not made by Brush Performance Alloys. Just provide us with a drawing, material requirement specifications, quantity and delivery requirements. Our manufacturing and engineering capabilities include:

- Bearing Design
- Design Assistance
- CAD
- Machining (milling, planing, drilling, tapping, gun drilling, turning, honing, centerless grinding, precision machining, sawing, broaching, etc.)
- Open and Closed Die Forging
- Investment, Sand and Centrifugal Casting
- Extruded Shapes
- Electron Beam and TIG Welding
- Brazing
- Wire EDM
- Waterjet Cutting

The custom fabrication department can be reached through the sales department at 216.486.4200, by e-mailing brushalloys-sales@materion.com, through the website at www.materion.com/BrushAlloys or by contacting your local Brush Performance Alloys representative.

Customer Technical Service

Support Staff

Brush Performance Alloys clearly differentiates itself from other material suppliers by providing an unmatched level of customer support. With unparalleled technical expertise and global service, we are the first choice for providing materials that work in the most demanding applications. We are more than a material supplier, we are a strategic partner in the growth and success of your business. Our technical service center is prepared to extend its considerable technical expertise to your staff. Whether you need design assistance, failure analysis or educational programming, our technical staff of metallurgists, mechanical engineers and application engineers is here to help. Put us to the test and see how our technical services team can perform for you.

Material Selection

We can assist you in evaluating through the large variety of high performance alloys and help select materials that will provide the best solution for your application, performance goals, processing criteria and cost considerations.

Fabrication and Processing Assistance We have application-specific technical specialists that assist customers with any problems they may experience in processing our materials. We can provide you with detailed guidelines and information on operations such as machining, welding, brazing, soldering, heat treating, cleaning, EDM, etc. Much of this information is available in the form of brochures or technical briefs.

Technical Seminars Built to Suit Brush Performance Alloys can design a seminar to suit your requirements in areas of metallurgy, contact design, plastic molding, plating and surface finishing, bearing design and many others. You choose the topics based on your particular needs. We will customize the content to address the precise aspects that pertain to your operation. We offer the expertise you require and the ability to put it to work in your environment

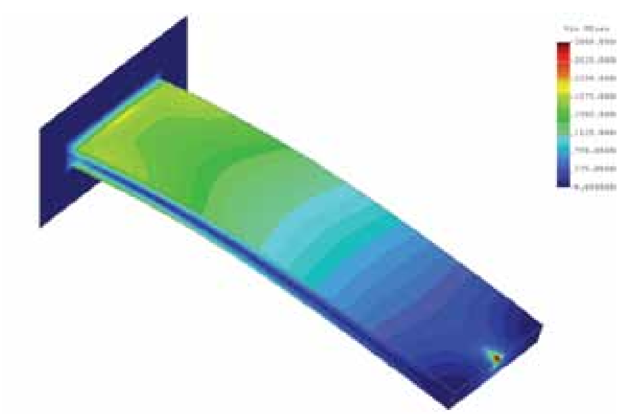
Material Samples Often, we will be able to provide you with small sample quantities of material for prototypes or experimental purposes.

Materion Brush Performance Alloys Value-Added Service

Design Assistance and Review We will review your designs in order to verify the suitability of the design and material for the application and help identify potential problems before a single part or prototype is made. We have extensive experience performing finite element analysis (FEA) on customer designs. If a problem is found, we will offer you advice on how to improve the performance. We can provide you with the following:

- Linear and Nonlinear Stress Analysis (contact, maximum stress, contact force, permanent set, etc.)
- Thermal Analysis (transient and steady state)
- Dynamic Analysis (mode shapes, natural frequencies, etc.)
- Material Property Data (stress relaxation, fatigue, etc.)
- FEA Input Data (stress-strain curves, thermal properties, etc.)

You also may wish to rely on our expertise in FEA if you need an independent confirmation on your own design and analysis work. All that we require to complete an analysis is an electronic model or dimensioned drawing of the part and a description of the loads and boundary conditions.



Example of FEA Stress Distribution Plot

Design Tools We have created a number of tools to assist you in your designs. These tools include but are not limited to the following:

- Connector Engineering Design Guide
- Online Bearing Design Guide
- Cantilever Beam Analysis Spreadsheets
- Temperature Rise Calculation Spreadsheets

Infrared (IR) Camera For plastic molding applications, we can demonstrate at your facility the use of an infrared camera to shoot images of the parts coming out of the mold. We will review the data with you to determine hot spots that can be eliminated by the use of Materion Brush Performance Alloys' MoldMAX® materials. A follow-up image will show the improvements in mold cooling after MoldMAX® is inserted in the mold, with corresponding benefits of reduced cycle time and decreased part warpage.

Example of IR Camera Temperature Plot

Technical Literature We continuously update and publish our technical literature in order to aid our customers in understanding our material and its processing. This includes:

- Technical Briefs
- Technical Tidbits Newsletter
- Product Brochures and Data Sheets
- Case Studies and Application Reports

Technical Projects We will work with customers to design and carry out technical or research projects on our materials.

Safe Handling Information Backed by Materion Brush Performance Alloys' product stewardship organization, we can provide you with the latest information on how to work safely with our materials.

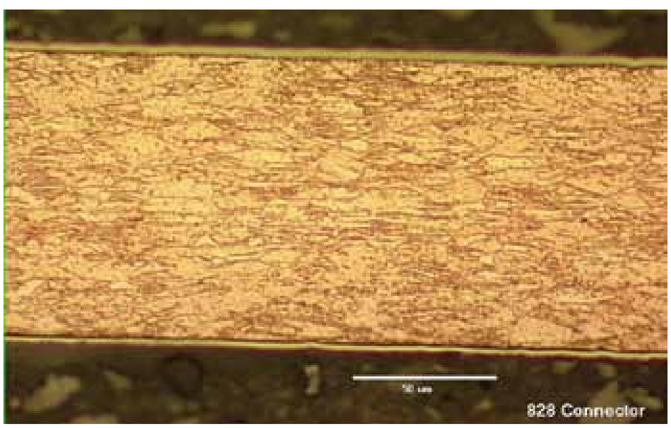
The customer technical service department may be reached at 800.375.4205 from the US and Canada or at +1.216.692.3108 from international locations. You also may contact this department through the design center on Materion Brush Performance Alloys' website at www.materion.com/BrushAlloys, by sending an e-mail to brushalloys-techservice@materion.com, or through your local Brush Performance Alloys representative.

Other Services

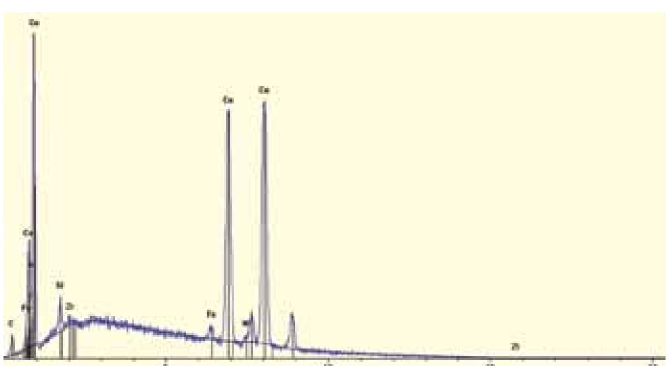
Failure Analysis and Research Capabilities

Our Alloy Technology laboratory in Elmore, Ohio, is well equipped with analysis tools to provide material evaluations and detailed failure analysis. We have the technology available to help identify our customer's problems and recommend possible solutions. Our facilities include equipment capable of mechanical, physical and chemical testing:

- Metallography
- JEOL JSM 6300V Scanning Electron Microscope (SEM) with Energy-Dispersive X-ray Spectroscopy (EDS) capability
- Mechanical Testing (tensile testing, hardness, fatigue, stress relaxation, formability, etc.)
- Physical Testing (surface roughness, electrical conductivity, die penetrant inspection, etc.)
- Heat Treating
- Chemical Composition
- Wear / Tribological Testing



Etched Metallographic Cross Section



Example of EDS Scan using SEM

Manufacturing Services

For copper beryllium requirements beyond those described in the Product Guide, our manufacturing facilities and service centers are prepared to meet your special needs. Examples include the following:

- Traverse winding
- Tension leveling of cold rolled strip
- Near net shape sawing of billet, plate and rod
- Shearing to specific length
- Tin or solder coating

Industry Contacts and Certified Suppliers

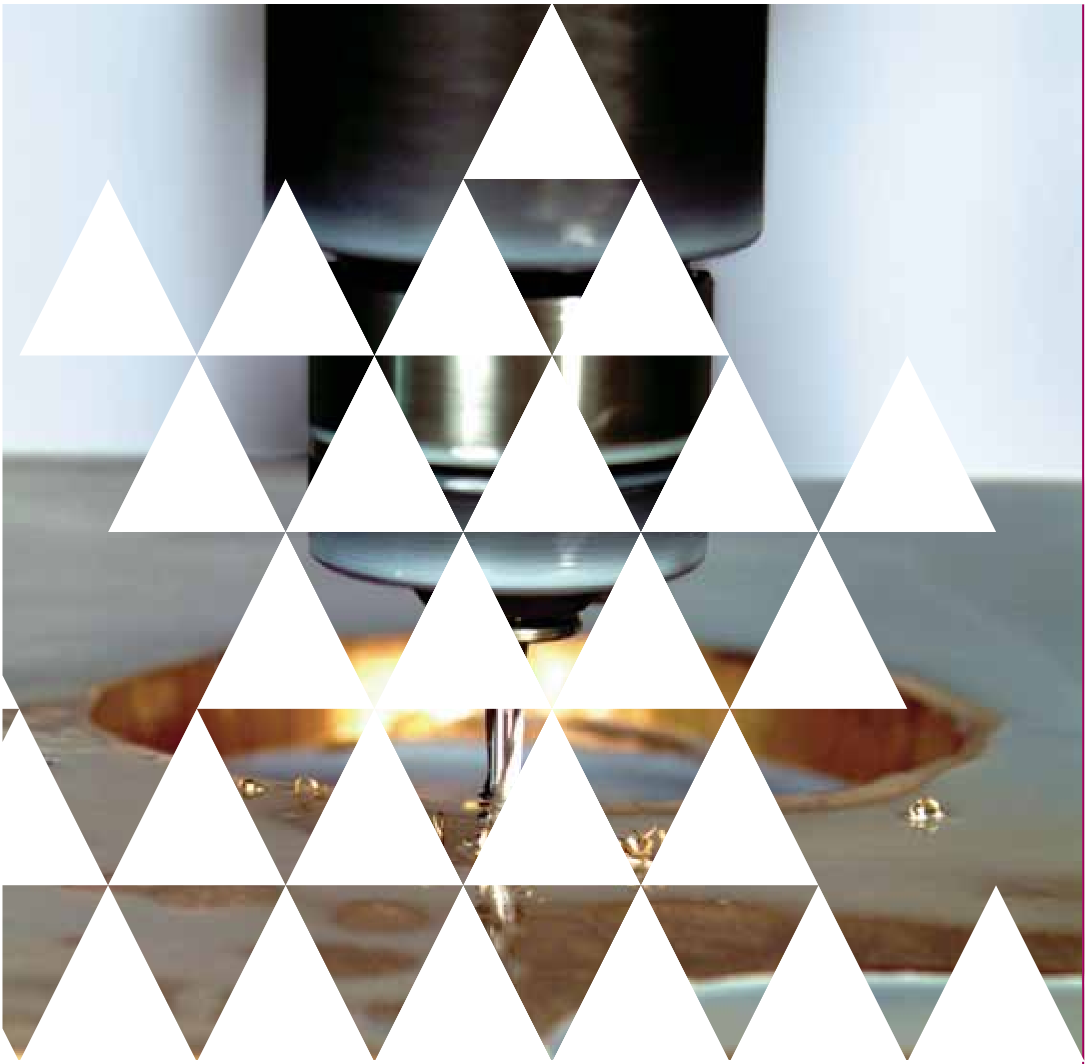
In response to a need beyond internal capabilities, Materion Brush Performance Alloys can refer the user to a supplier with demonstrated expertise in manufacturing copper alloy products with specialized equipment and technology. This includes vendors and problem solvers in a wide variety of areas including stamping, forging, extruding, heat-treating, casting, testing, design, etc.

Examples include the following:

- Fine wire drawing [for wire less than 0.050" (1.27 mm) diameter]
- Thin foil rolling [for strip less than 0.0015" (0.04 mm) thick]
- Thin wall tube redrawing [for tube less than 0.75" (19.05 mm) diameter]
- Multigauge strip contouring
- Prototype and production blanking and forming
- Photochemical machining
- Fixture age hardening
- Joining
- Inlay cladding
- Solder striping
- Electron beam welding
- Zone annealing
- Electroplating
- Machining
- Investment and Sand Castings

Contact a Brush Performance Alloys representative to learn more about our value-added services.

Processing and Fabrication Guide



Topics related to designing and working with Materion Brush Performance Alloys' products are highlighted in this section. The emphasis is on alloy and product performance in fabrication and service environments.

When more detail is needed, information is available in separate Brush Performance Alloys' publications.

Heat Treating Fundamentals

An awareness of the ways that composition, casting practices, hot work, cold work and thermal processes interact to synthesize properties and microstructure is useful in designing and working with heat treatable alloys. Small additions of elements such as beryllium, nickel, cobalt and tin to copper, activated by mechanical and thermal processing, result in strength exceeding that of most copper base alloys and many hardened steels. Furthermore, controlled mechanical working and specific thermal processing allow properties to be tailored to meet a broad range of requirements. These fundamental effects are explored on the following pages.

Copper beryllium, C18000 and MoldMAX V® copper nickel silicon chromium alloys, C19160 and Brush 1915® leaded copper nickel alloys, and nickel beryllium Alloy 360 are strengthened by precipitation hardening reactions. ToughMet® and the copper nickel tin alloys are strengthened by spinodal decomposition.

Solution Annealing

All strengthening heat treatments are the result of a thermally induced phase change in the material. The first step in making a material respond to heat treatment is solution annealing. This typically involves heating the metal to a high enough temperature to convert the microstructure into a single phase. A rapid quench to room temperature leaves the alloy in a supersaturated state. This process makes the alloy soft and ductile, helps regulate grain size and prepares the alloy for age hardening. Subsequent heating of the supersaturated solid solution causes precipitation of the strengthening phase and hardens the alloy.

Solution annealing is performed as part of the manufacturing process, and is usually not done by the end user. In fact, further attempts at solution annealing will compromise the ability to achieve peak properties after subsequent heat treatment.

Solution annealed material may then be subsequently cold worked into various wrought forms. For most products, the final precipitation hardening heat treatment would then be performed by the mill before sale to the customer. Some products are sold without the final heat treatment, and then must be heat treated by the customer. Please see the product guide section to see which tempers are available for each product.

Cold Working

Cold work in an age hardening alloy denotes plastic deformation at a temperature below the recrystallization temperature. A metalworking process changes the dimensions of a workpiece, typically in two directions, with rolling, drawing, bending and upsetting being prime examples of cold working operations. In contrast to hot working, cold work elongates grains in the working direction, and deformation effects accumulate. Cold work increases strength and hardness of copper alloys. A reduction in ductility, measured by elongation, accompanies this increase in strength.

The strengthening effects of cold work are especially important in age hardened products. Cold work increases the number of precipitation sites and thereby accelerates age hardening. Elongation declines as cold work increases, but at a much lower rate than in the unaged product. However, cold work does provide increased ductility in precipitation hardened alloys at a given strength level.

During processing of mill products, cold working produces excellent dimensional precision and shape. Proper solution annealing of cold worked copper products under closely controlled conditions causes grain refinement and reduces property directionality. Incorporating a well engineered schedule of cold work and annealing cycles into our mill process ensures a product with precise dimensions and a well controlled microstructure.

Heat Treating Equipment

Age hardening normally does not require either controlled cooling or a special furnace atmosphere. Please be aware that the oxides that can form on the surface during heat treatment must be removed if surface treatments such as plating are subsequently required. A protective atmosphere is useful, especially when it is recirculated to reduce furnace thermal gradients. A low dewpoint atmosphere (-35°F / -37°C or less) or a reducing atmosphere with less than 15 ppm oxygen content are examples of conditions that economically aid heat transfer while minimizing post hardening cleaning requirements. Vacuum age hardening is difficult because of the non-uniform nature of radiant heating at low temperature.

Fixtures may be used for age hardening to prevent distortion. A salt bath provides the precise control needed for short-time high-temperature aging that results in minimum distortion and the production economies of a short cycle. Please contact Materion Brush Performance Alloys' Technical Service Department for further details or more information on distortion prevention.

Precipitation Hardening

Age hardening response depends on time, temperature and amount of cold work because strengthening is governed by precipitate size and distribution. For each alloy there is a temperature-time combination that is designated as standard practice because it produces a flat response curve at peak strength in a reasonable amount of time. Please see the Product Guide section for the proper time and temperature for each product.

Alloy 25 Copper Beryllium

The standard age hardening temperature for Alloy 25 is 600°F – 625°F (315°C – 330°C) for strip and wire products, and 600°F – 675°F (315°C – 357°C) for all other products. Two hours at temperature are required for cold worked products and three hours at temperature are required for annealed products. Age hardening at this time and temperature produces maximum strength for all tempers. Higher temperature achieves peak strength in shorter time, but the peak strength is reduced. Heating at lower temperature increases strength at a slower rate and, although high strength can be achieved, it requires excessive time.

Cold work improves the achievable strength levels for all aging temperatures. As the level of cold work increases, the time at temperature to achieve peak strength decreases. Ductility decreases as strength increases. Overaging improves ductility, but there is evidence that impact toughness is reduced.

Age hardening increases the density of the high strength alloys slightly as a result of the precipitation reaction. This density change is accompanied by a decrease in linear dimensions of approximately 0.2%. The dimensional change in the other heat treatable alloys is negligible for most applications with the exception of Alloy 360 nickel beryllium.

High Conductivity Copper Beryllium

The standard age hardening treatment for Alloys 3 and 10 is 900°F - 925°F (480°C - 500°C) for 2 to 3 hours: two hours for cold worked and three hours for annealed products. The temperature ranges for age hardening are higher for these alloys than for Alloy 25. The stability of the strengthening phase at elevated temperature results in high resistance to creep and stress relaxation in this alloy family.

Alloy 360 Nickel Beryllium

The heat treat response of Alloy 360 nickel beryllium is similar to that of high strength copper beryllium. Peak properties are achieved by aging at 925°F (500°C). The annealed and ¼ H tempers require 2.5 hours at this temperature, while the ½ H and H tempers require 1.5 hours. A controlled atmosphere is best for maintaining a bright surface. Alternatively, the material may be pickled after age hardening to restore the surface.

Alloy 360 experiences a volume change during age hardening similar to that of the Alloy 25 copper beryllium. Fixtures may be required to prevent parts from distorting during heat treatment.

Spinodal Decomposition in BrushForm® 96 and 158

While the preceding materials are strengthened by precipitation age hardening, BrushForm® 96 and BrushForm® 158 are strengthened by spinodal decomposition. In precipitation age hardening, strengthening occurs when small amounts of a second phase precipitate out of a supersaturated solid solution when exposed to the aging temperature. **Spinodal decomposition** takes place "spontaneously" and needs no incubation period. A continuous diffusion process, in which there is no nucleation step, produces two chemically different phases with an identical crystal structure. The two phase structure in the spinodally hardened alloy is very fine, invisible to the eye and continuous throughout the grains and up to the grain boundaries.

The high strength of the copper nickel tin alloys resulting from spinodal decomposition has been attributed to the coherency strains produced by the uniform dispersions of tin-rich phases in the copper matrix. A three-fold increase in the yield strength over the base metal results from spinodal decomposition in the copper nickel tin alloys. ToughMet® is provided in the fully hardened condition. No heat treatment is required.

BrushForm® 96 is heat treated at 700°F (370°C) for 2 hours. BrushForm® 158 in the solution annealed (TX00) or quarter hard (TD01) temper is heat treated for 3 hours at 700°F (370°C). The remaining tempers of BrushForm® 158 are heat treated for 3 hours at 650°F (345°C).

Unlike precipitation hardening, spinodal decomposition produces a continuing reduction in elongation during overaging. Therefore, care should be taken to avoid overaging BrushForm® 96 or BrushForm® 158. Detailed heat treat response curves are available. Please consult the technical service department for more information.

Another significant difference is that spinodal decomposition does not result in significant volume change, unlike precipitation age hardening. Since there is no change in volume, parts made from BrushForm® 96 or BrushForm® 158 will not appreciably distort during heat treatment.

BrushForm® 96 and BrushForm® 158 can be aged in air without tarnishing, but a protective atmosphere is recommended. Flux is required for soldering.

Non-Standard Heat Treatment

Departures from standard practice, either higher or lower temperatures for example, may be used to meet requirements that permit less than maximum strength or hardness. A temperature higher than standard causes more rapid precipitation and thus faster strengthening, albeit at a lower peak strength. Similarly, a lower temperature results in a slower strengthening rate.

In some applications not requiring maximum properties, short time high temperature hardening cycles can be employed. The temperature-time conditions, including heat up and cool down rates, are critical to hardening rate and intensity. Consequently, when using a special age hardening method, the temperature-time should be accurately established with sample lots before production begins. Cessation of aging at times shorter than the time needed to achieve peak strength is known as "underaging." This results in a lower final strength. Toughness, fatigue strength and in some cases corrosion resistance, benefit from the underaged microstructure.

"Overaging" involves heating for a time longer than needed to achieve peak strength. This results in precipitate coarsening and consequently in hardness and strength below peak values. Electrical and thermal conductivities, and dimensional stability are maximized by overaging. Caution is required to avoid severe overaging.

Stress Relieving

Residual stress, which may arise from certain types of deformation after age hardening, may be thermally relieved without loss of hardness. Heating at temperatures of 300°F to 400°F (150°C to 200°C) for up to two hours is generally adequate to provide moderate stress relief. Note spinodally decomposed materials have inherently good stress relaxation resistance. A consequence of this is that there is no procedure to stress relieve parts made from BrushForm® 96, BrushForm® 158 or ToughMet®.

Please contact the Technical Service Department for additional information on overaging, underaging, stress relieving, distortion prevention or detailed heat treat response curves. The technical service department may be reached at 800.375.4205 from the US and Canada or at +1.216.692.3108 from international locations. You also may contact this department through the design center on Materion Brush Performance Alloys' website at www.materion.com/BrushAlloys, by sending an e-mail to brushalloys-techservice@materion.com, or through your local Brush Performance Alloys representative.

Forming of Strip

The accompanying tables are a guide to temper selection based on forming requirements. A material's formability rating (R/t) is expressed in terms of the ratio of the bend radius (R) to the strip thickness (t). This value defines the sharpest radius that can be formed without failure. Materion Brush Performance Alloys publishes forming limits in a 90° bend to which its strip products will form without fracture. Larger R/t ratios indicate less formability since a larger forming radius is required. Therefore, an R/t value of 0 means the material can be formed around a sharp corner (zero radius) without failure. An R/t of 1.5 would require a punch radius of at least 1.5 times material thickness. As in the case of a material's ductility, formability is heavily dependent upon an alloy's strength. As strength increases from cold rolling or mill hardening, formability decreases (increasing R/t ratio) and the formability becomes anisotropic (directional).

For the purpose of these tables, the bend test is acceptable if there is no evidence of fracture, cracks or skin bursts when examined under 30X magnification. A moderate amount of surface roughness commonly referred to as "orange peel" is considered acceptable. The bend test is failed if fractures, cracks or skin bursts are evident when examined under 30X magnification.

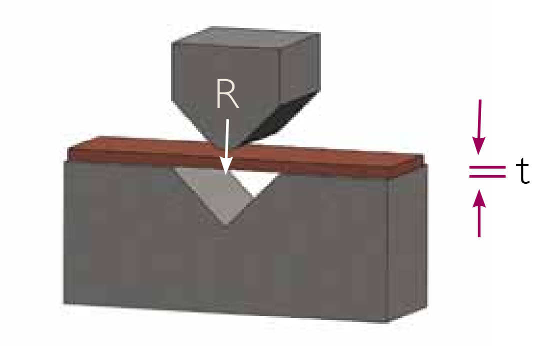
Annealed strip has excellent formability with both longitudinal and transverse bends posing no forming barrier. Certain mill hardened tempers also have low directionality. Because of this isotropy, special consideration does not have to be given to the manner in which parts are stamped relative to the rolling direction. In many instances this will permit nesting of parts to allow efficient material utilization.

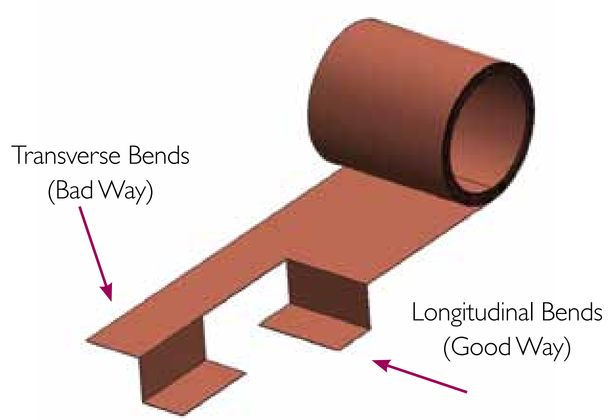
The tooling requirements for stamping and drawing copper beryllium or copper nickel tin are the same as those required for any copper base alloy with similar hardness. Tools should be kept sharp, with punch to die clearances of about 5% of the stock thickness (or 2.5% per side).

This practice will minimize edge burr formation and residual stress during blanking or shearing. Burrs should be removed prior to age hardening since they can be the source of fatigue failure in highly stressed parts. Draft angles should be about 1/2 degree per side greater than those used for phosphor bronze or brass to preclude copper buildup on the punches, which could change die clearances. Lubricants can prolong die life, but those containing sulfur may cause staining, so they should be removed immediately after stamping.

The stamping and forming practices for Alloy 360 nickel beryllium are the same as those used on other nickel based alloys. Springback becomes more pronounced as temper and strength increase. Springback can be controlled by overforming bends to achieve the required angles. For a given punch radius, springback decreases with increasing strip thickness.

Brush Performance Alloys' formability information is intended to be used as a guide for selecting the appropriate temper for an application. If the inside angle of a bend is obtuse, a radius smaller than the recommended value can be used. If the angle is acute, a larger radius may be required. The quality of the bend also can be influenced by the forming method used. For example, forming the bend in several steps, instead of just one, or rolling the material around the radius, will produce tighter bends than the R/t ratios would indicate. Also influencing the quality of a bend is strip width; very narrow strip will form better than wide strip. Strip with a width to thickness ratio less than about 10:1 will exhibit improved formability. Thicknesses less than 0.004 inches (0.1 mm) will exhibit greatly improved formability.



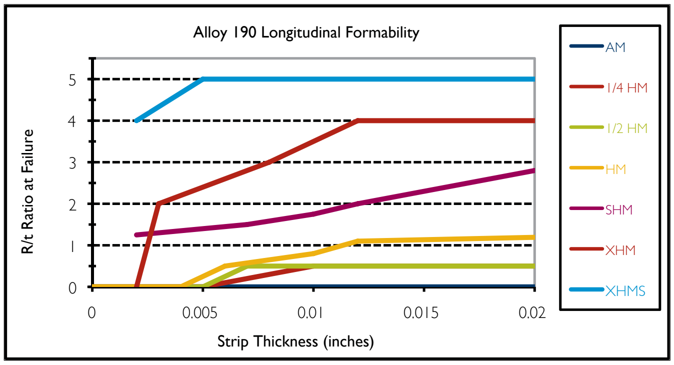


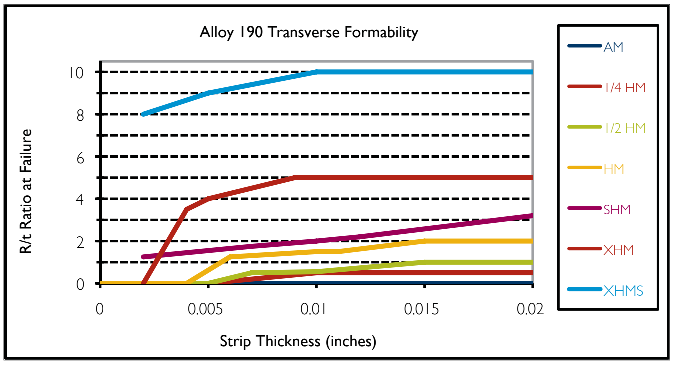
NOTE: Formability ratios are valid for strip up to 0.050 inches (1.27 mm) thick. Strip less than 0.010 inches thick may form somewhat better than shown. Values reflect the smallest punch radius that forms a strip sample into a 90° "vee"-shaped die without failure. R = punch radius, t = stock thickness

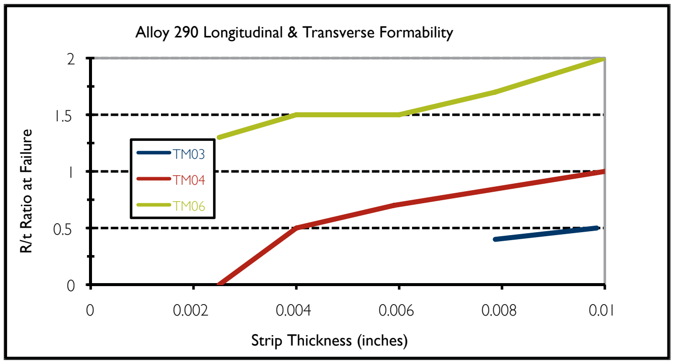
Guide to Strip Alloy Formability

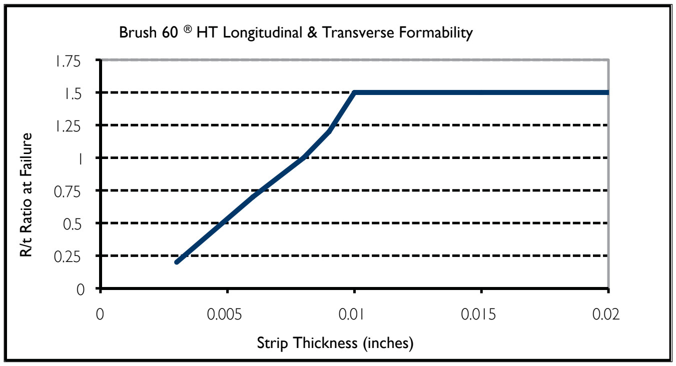
Formability Rating	Specific Formability	Alloy and Heat-Treatable Temper	R/t Ratio for 90° Bend		Alloy and Mill Hardened Temper	R/t Ratio for 90° Bend	
			Direction of Bend			Direction of Bend	
			L	T		L	T
Excellent	Used for deep drawn and severley cupped or formed parts	25 A BrushForm® 96 A BrushForm® 158 A 360 A	0 0 0 0	0 0 0 0	-	-	-
	As formable as the annealed temper but easier to blank	25 1/4 H BrushForm® 158 1/4 H 360 1/4 H	0 0 0	0 0 0	290 TM02 BrushForm® 158 TM00 BrushForm® 158 TM02 360 MH2	0 0 0 0	0 0 0 0
Very Good	Used for moderately drawn or cupped parts	BrushForm® 158 1/2 H 25 1/2 H 360 1/2 H BrushForm® 96 1/4 H	0 0.5 0.7 1.1	0.5 1.0 1.2 1.7	190 AM BrushForm® 96 TM00 174 1/2 HT 190 1/4 HM BrushForm® 96 TM02 290 TM03 360 MH4 Brush 60® 3/4 HT 290 TM04 190 1/2 HM 3 AT 390E® EHT ≤0.002" (0.05 mm)	0 0.2 0.5 0.5 0.5 0.5 0.5 0.7 0.7 0.5 1.0 1.0	00 0.2 0.5 0.5 0.5 0.5 0.5 0.7 0.7 1.0 1.0 1.0
Good	Formable to a 90° bend around a radius less than 3 times the stock thickness	360 H BrushForm® 96 1/2 H BrushForm® 96 H BrushForm® 158 H 25 H	1.2 1.5 1.5 0.5 1.0	2.0 2.0 2.5 3.0 3.0	BrushForm® 96 TM04 360 MH6 BrushForm® 158 TM04 Brush 60® HT 290 TM06 360 MH8 390® HT ≤0.004" (0.1mm) 3 HT 190 HM BrushForm® 158 TM06 360 MH10 390E® EHT ≤0.004" (0.10 mm) 360 MH12 BrushForm® 96 TM06	1.0 1.0 1.0 1.5 1.5 1.2 2.0 2.0 2.0 2.0 1.5 2.0 2.0 2.5	1.0 1.2 1.5 1.5 1.5 1.6 2.0 2.0 2.0 2.0 2.2 2.5 3.0 3.0
Moderate	Suitable for light drawing; used for springs	-	-	-	290 TM08 190 SHM 390E® EHT ≤0.006" (0.15 mm) 390E® EHT ≤0.010" (0.25 mm) 174 HT 390® HT >0.004" (0.1mm) 390E® EHT >0.010" (0.25 mm) 190 XHM	3.5 2.8 2.5 3.5 1.2 3.5 4.0 4.0	3.0 3.2 3.5 4.0 5.0 5.0 5.0 5.0
Limited	For essentially flat parts; forming requires very generous punch radius	BrushForm® 96 TD08	3.0	6.0	BrushForm® 96 TM08 BrushForm® 158 TM08 190 XHMS	5.0 5.0 5.0	7.0 8.0 10.0

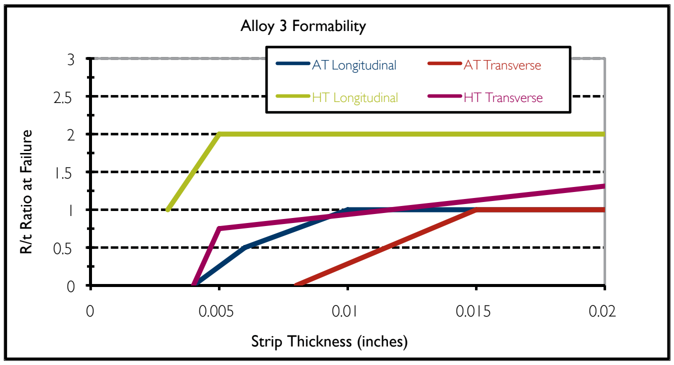
Formability vs. Thickness Curves

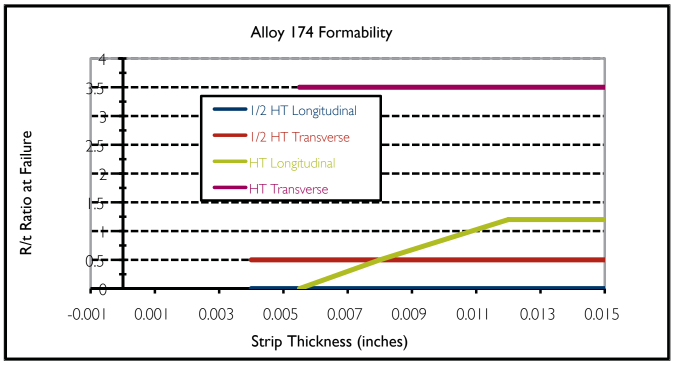


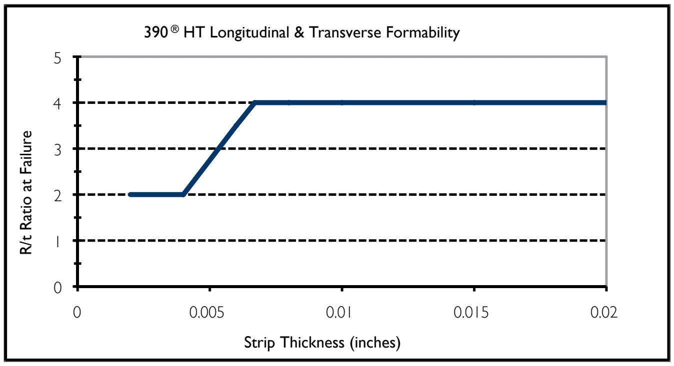


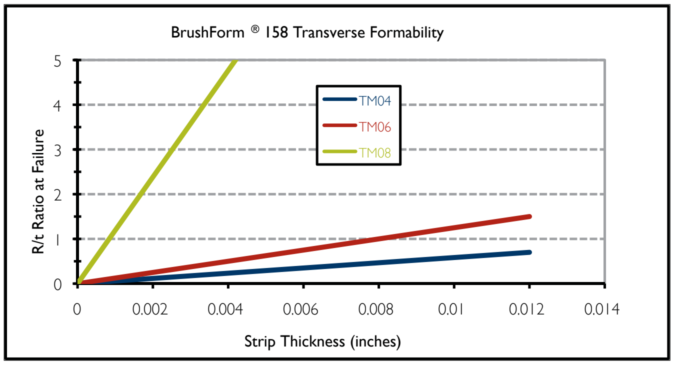












Cleaning and Finishing

Copper beryllium and copper nickel tin display all the desirable plating and joining characteristics for which the copper alloys are well known. However, because these alloys are frequently specified for precision applications, surface cleanliness should be considered a critical factor when articles are to be plated, or joined by soldering, brazing or welding. All foreign substances, including oil, grease, paint, dust, dirt, tarnish and oxide, must be removed before these operations are undertaken. This cannot be emphasized too strongly because most problems related to plating or joining quality can ultimately be traced to improper or inadequate cleaning.

Cleaning

The first step in the preparation of these alloys for subsequent plating or joining is the removal of all soils, particularly oils and greases. These are normally present as residual traces of lubricants used during machining or forming or as contaminants from exposure to oil-mist-laden shop atmospheres. Sulfur-bearing lubricants, if not removed quickly, can stain copper beryllium. Note that water soluble oils are easier to remove. Surface soils also result from handling; fingerprints and oily work gloves are common offenders.

Conventional cleaners, such as organic solvents and alkaline solutions, are normally adequate for removing oily residues. Use of these cleaners should be pursuant to local regulations. Normal care should be taken to insure that solution concentrations, temperatures and flow rates are within proper limits and that recirculation or filtration systems are adequately maintained. Vapor degreasing is especially effective for removing oils and greases. Trisodium phosphate and similar alkaline solutions, including the many available proprietary formulations, are likewise satisfactory, and ultrasonic or electrolytic agitation can supplement these media for best results. Cleaning solutions should be thoroughly rinsed from all surfaces. Any questions regarding a cleaner's effectiveness should be resolved by testing on representative samples.

Like all copper alloys, these materials can form a thin surface oxide, or tarnish, when exposed to air. Tarnish formation is accelerated by the presence of moisture and elevated temperature. Oxidation normally results from heat treatment. Even when protective atmospheres are used, the formation of sufficient surface oxides to cause plating or joining problems should be anticipated. Mill-hardened strip however, is thoroughly cleaned and inhibited before delivery.

Copper beryllium surface oxides take two forms: beryllium oxide, present on surfaces exposed to the high temperatures needed for solution annealing; and combinations of beryllium and copper oxides, present on parts after precipitation hardening. The removal of a pure, continuous beryllium oxide will not be considered here since solution annealing is rarely performed by the user. For special cases, such as removal of oxides formed during annealing or welding, contact Materion Brush Performance Alloys for appropriate cleaning procedures.

BrushForm® 158 and ToughMet® will form a mixed copper oxide and nickel oxide layer. The nickel oxide layer is self-limiting, which minimizes the formation of tarnish on the surface and keeps the surface readily solderable.
The surface of copper beryllium or copper nickel tin can be prepared for plating or joining, or simply restored to its original, lustrous appearance, with the following procedure.

Step 1 – Immerse parts in a 120°F - 130°F (49°C - 54°C) aqueous solution of 20-50 volume % sulfuric acid. Immersion time should be that required to remove dark coloration and provide the desired response or appearance after a few minutes.

Step 2 – Rinse thoroughly and dry.

When necessary, parts made from mill hardened copper beryllium or copper nickel tin can be readily cleaned by the above method. In all cases care should be taken to avoid excessive immersion time, temperature or high acid concentration since these may remove measurable amounts of metal.

Electroplating, Coloring and Polishing

Nickel, gold, silver, tin, chromium, copper and other metals are commonly electroplated on these alloys. Materion Brush Performance Alloys supplies electroplated strip or can direct an interested user to an experienced supplier for discrete part, electroless or selective plating. Some frequently used plating pretreatments are as follows.

Alloys other than M25:

Step 1 – Cathodically clean with a hot alkaline solution.

Step 2 – Rinse in cold water.

Step 3 – Immerse for 10-15 seconds in a 120°F - 130°F (49°C - 54°C) aqueous solution of 20-25 volume % sulfuric acid (H_2SO_4) plus 2-3 volume % hydrogen peroxide (H_2O_2).

Step 4 – Rinse in cold water.

Alloy M25

Step 1 – Cathodically clean with a hot alkaline solution.

Step 2 – Rinse in cold water.

Step 3 – Immerse for 10-15 seconds in a room temperature 10 to 12 volume % fluoboric acid (HBF_4) aqueous solution.

Step 4 – Optionally apply a cyanide copper strike for adhesion as recommended for most copper alloys. Copper beryllium products also can be colored by all conventional techniques used for copper alloys. Satin black oxide to an artificial patina are examples.

Wet brushing, buffing and electropolishing are used to produce extremely fine surface finishes on copper beryllium. Best electropolishing results are obtained with a nitric acid/ methanol electrolyte at -70°F (-55°C). A phosphoric acid, chromate electrolyte can be used at room temperature, but this may leave certain intermetallic particles in relief. Phosphoric, nitric and acetic acids can be mixed to produce a chemical polishing solution for use at 160°F (70°C).

Alloy 360 nickel beryllium can be cleaned with the following procedure:

Step 1– Immerse parts for 1 hour in a 160°F (70°C) aqueous solution of 50 volume % sulfuric acid (H_2SO_4).

Step 2 – Rinse thoroughly and dry.

Joining

Soldering and brazing are important assembly techniques for copper beryllium and copper nickel tin. As with any heat treatable alloy, heating time and temperature during joining must be standardized and controlled.

Welding copper beryllium offers advantages over other structural alloys particularly those depending on cold work for strength. In copper beryllium, a welded joint can retain 90% or more of the base metal mechanical properties. Sensitization, surface depletion and other difficulties associated with welding other alloys are not problems with copper beryllium.

Soldering

Soldering is normally specified when the anticipated service temperature is below about 350°F (175°C) and electrical and thermal continuity are difficult to insure with a mechanical joint. Soldering lends itself to automation and can be performed by heating with resistance, induction, infrared or flame. Application techniques include immersion, wave, vapor phase and others. Copper beryllium and copper nickel tin can be soft soldered after age hardening without detriment to mechanical properties.

Copper beryllium and copper nickel tin can be soldered with most standard fluxes (adequate to remove room temperature oxides and tarnish), but flux should never be relied upon as a substitute for a proper cleaning treatment. Activated rosin fluxes (RMA or RA grades) are recommended, but these should be removed by hot water rinsing after soldering to prevent corrosion of other components.

It is good practice to join parts as soon after surface preparation as practical. If delays are unavoidable, parts should be stored in clean, dry locations free from acid, sulfurous or ammonia fumes. Shelf life can be extended by inhibiting the surface with benzotriazole (BTA), or by precoating with pure tin or tin-lead solder.

Copper beryllium and copper nickel tin are solderable with all common leaded and lead-free solder compositions. Alloys containing 60% tin-40% lead (60/40) are generally recommended for electronic assemblies, especially when high speed processes are employed. Both copper beryllium and copper nickel tin can easily withstand the higher temperatures required when using lead-free solders. Additional preparation information is available in Materion Brush Performance Alloys' TechBrief, "Soldering Copper Beryllium."

Brazing

Compared with soldering, brazing provides higher strength and superior resistance to thermal exposure at moderately elevated temperatures.

Since brazing is performed at relatively high temperature, it is preferable that parts be brazed before age hardening. With a rapid brazing cycle, hardened copper beryllium and copper nickel tin can be joined effectively. Time at temperature should be no more than the minimum needed to insure braze alloy penetration. Surface cleanliness is important for achieving sound brazed joints. The surface must be free from all traces of dirt and oil and should be cleaned prior to brazing. A 15 to 20% nitric acid solution in water, followed by thorough water rinsing works well.

Brazing may lightly oxidize exposed surfaces. This oxide can be removed by immersion in 50% sodium hydroxide at 265°F (130°C), followed by normal acid cleaning.

Furnace, induction and torch brazing are common methods. Braze integrity depends on geometrical factors such as joint design, assembly size and thermal parameters such as heat input and dissipation rates. Heat sinks may be used to confine heat to the joint area. Small brazed assemblies may permit short time, high temperature age hardening to be incorporated into the brazing cycle. However, the brazing cycle must be kept short to avoid overaging. Larger furnace brazed parts require quenching after brazing to permit subsequent age hardening. The brazing temperature should not exceed 1450°F (790°C) for high strength copper beryllium, 1600°F (870°C) for high conductivity copper beryllium, and 1500°F (815°C) for copper nickel tin. Additional preparation information is available in Materion Brush Performance Alloys' TechBrief, "Brazing Copper Beryllium."

Welding

Welding is a useful joining process for copper beryllium and copper nickel tin, but careful metallurgical planning is essential. Consideration must be given to joint design, preheat (below age hardening or spinodal decomposition temperature), weld technique and post welding practice. The heat affected zone in copper nickel tin will be overaged and have very low ductility so welding should be done only when absolutely necessary.

These alloys are easily resistance welded by spot or seam welding to itself or other metals. Electron beam, ultrasonic and laser welding also are performed. Both Nd:YAG and CO_2 lasers may be used. Copper beryllium has a reflectivity similar to pure copper, so high power is required. Reflectivity is less of a concern with copper nickel tin.

Fusion welding by tungsten arc inert gas (GTAW/TIG), metal arc inert gas (GMAW/MIG), plasma-arc and electron beam are routinely performed on copper beryllium. Post welding thermal hardening treatments are common unless maximum strength in the joint area is not required, as when the joint is made in a low stress area.

Strip is often joined to itself, other strip material, or electrical contact buttons by resistance welding or spot welding.

Pre-Welding Preparation

Best results are obtained with a clean surface, free of dirt, oil, paint, grease, tarnish and oxide. Conventional cleaning, such as solvent or vapor degreasing, is effective in removing organic contaminants. Aggressive brushing, abrasive blasting or acid pickling is required for adherent contaminants such as oxides.

Cleaned parts should be welded immediately. If a delay is unavoidable, they should be stored in a protected environment away from shop dust, acid and sulfurous or ammonia fumes.

Additional preparation information is available in Materion Brush Performance Alloys' TechBrief, "Cleaning Copper Beryllium."

If performing weld repair, all existing cracks should be removed by machining, and all edges should be rounded.

The material should be preheated to minimize the potential for cracking during the welding process. Copper beryllium should be preheated to a temperature of 400°F (200°C). Copper nickel tin should be preheated to 300°F (150°C).
WeldPak® copper beryllium should be used as the filler metal for welding copper beryllium. When welding copper beryllium to steel, an aluminum bronze filler metal is often used.

When welding copper nickel tin, the recommended filler metal is ERNiCu-7 rod, such as Monel® Filler Metal 60 (produced by and a registered trademark of Special Metals Corporation). WeldPak XL may also be used, although there will be a color difference between the repair and the surrounding metal when welding MoldMAX XL®. WeldPak XL has some tendency to form porosity, so it is recommended that the weld pool be worked slowly to eliminate gas bubbles.

Additional information is available in Materion Brush Performance Alloys' TechBriefs, "Welding ToughMet", "Welding Copper Beryllium"; and "Weld Repair of MoldMAX® and PROtherm™ Mold Materials".

Post-Weld Heat Treatment

In a weld-repaired part, the weld zone will be considerably softer than the surrounding material. A post-weld heat treatment would be necessary to restore hardness. For copper beryllium, the part should be aged for 2-3 hours at 600°F (315°C). This will bring up the hardness of the weld zone, although the hardness of the heat affected zone adjacent to the weld will still be low, since this area is overaged. The heat affected zone can only be restored to full hardness by solution annealing, quenching, and re-aging the entire welded part, which is often not practical.

For the copper nickel tin alloys, a post weld heat treatment of 3 hours at 700°F (370°C) is often used to partially restore the hardness of some of the heat affected zone. The Monel® Filler Metal 60 is not hardenable, so if that is used as the filler metal, the weld zone will have considerably lower hardness than the surrounding metal. Do not post-weld heat treat the TS tempers of ToughMet as this will overage the bulk of the material and destroy its properties.

If no postweld aging is performed, a stress relief heat treatment of 3 hours at 500°F (260°C) can be done to minimize the potential for cracking in the welded part.

Please contact the Technical Service department at Materion Brush Performance Alloys for additional information and detailed Technical Briefs on brazing, soldering, welding, cleaning and heat treating.

Machining

Copper beryllium and copper nickel tin can be machined at metal removal rates as high or higher than published values for free-cutting copper alloys or stainless steels. This can be done without sacrifice in tool life provided that proper tools and cutting fluids are used. Copper beryllium alloys should always be machined wet (with some coolant). Guidelines for effective metal removal are provided in the tables on the next two pages.

High metal removal rates sometimes present chip removal problems with cold worked or annealed products, particularly those without lead content. Long, stringy, tough chips are difficult to handle. To avoid this difficulty, non-leaded copper beryllium is usually machined in the age hardened (AT or HT) condition. In addition to improved chip control, age hardening and cleaning after machining are eliminated. Alternately, Alloy M25 in any temper offers improved chip control due to carefully controlled addition of lead. This alloy is well suited to automatic machining operations, since the lead in the alloy reduces tool wear and eliminates chip clogging. However, M25 is not weldable.

As with many high performance alloys, machining can work harden the surface of a copper beryllium or copper nickel tin workpiece. Shallow depth of cut or a dull or rubbing tool can accentuate this hardening. For best results, be sure that the tool is sharp and that the feed rate is sufficiently high that each subsequent cut penetrates below the work hardened layer.

Cutting tools should be sharp and have a positive rake angle between 5 and 20 degrees for best performance. The use of chip breakers for chip control during turning is recommended.

The use of a cutting fluid as a coolant and for chip removal is recommended for longer tool life and improved surface finish. Water soluble oils and synthetic emulsions are commonly used coolants. Although the best finishes are obtained from sulfurized oils, these oils will discolor copper beryllium and copper nickel tin (as well as other copper alloys). The stain is not harmful, but oil should be removed after machining, particularly if the parts will be subsequently age hardened.

These alloys also are commonly machined by other conventional methods such as abrasive machining or grinding using traditional equipment. Selection of grinding wheel, speed, metal removal rate and coolant follows guidelines established by grinding wheel manufacturers and others. Grinding should always be done wet.

These alloys also are machinable by nontraditional methods. Photochemical machining of strip is established technology with chemically resistant masks that were developed specifically for copper alloys. Electrical discharge machining, using either an electrode form or a traveling wire, and electrochemical machining of all product forms are practiced.

ToughMet® alloys are typical short chip copper alloys. They machine very well, especially when aided with chip breakers. ToughMet® 2 and MoldMAX XL® can be machined at extremely high surface speeds with carbide tools. Shops equipped with high speed machines with sufficient horsepower can remove large amounts of material in short periods of time. Copious amounts of coolant are required to achieve these high speeds. ToughMet® 3 does not have the thermal conductivity of ToughMet® 2 and, consequently, high speed roughing is not recommended.

ToughMet® 2 and MoldMAX XL® can be turned with C2 grade carbides. This choice of carbide is recommended in high speed machining applications where heat generation may lead to fracture and premature deterioration of the insert. ToughMet® 3 should be machined with a harder grade of carbide to minimize wear. Grade C5 is recommended for most applications. Chip breakers incorporated into the insert aid in producing a very short, manageable chip.

Surface finishes better than 100 micro-inches (2.5 microns) Ra are possible with feeds as large as 0.004 inch (0.1 mm) per revolution. Liquid coolant is recommended. **Positive rake angles are strongly recommended.**

Milling is best performed with a carbide inserted milling cutter. The same cutters used for P20 tool steels can be employed; however, a positive rake angle is advantageous.

Recommended Speeds and Feeds for Machining Brush Performance Alloys Copper Beryllium Alloys

Operation	Cutting Speed		Feed Rate		Depth of Cut		Tool Material
	ft/min	m/min	in/rev	mm/rev	in	mm	
Alloys 25, M25 and 165							
Turning							
A	1500-1800	450-550	0.010-0.020	0.25-0.51	0.025-0.050	0.64-1.27	C-2
H	1200-1500	365-450	0.010-0.020	0.25-0.51	0.025-0.050	0.64-1.27	C-2
AT, HT	900-1200	275-365	0.010-0.020	0.25-0.51	0.025-0.050	0.64-1.27	C-2
Drilling							
A	200-350	60-100	0.002-0.009	0.05-0.23	-	-	H.S.S.
H	150-300	45-90	0.002-0.009	0.05-0.23	-	-	H.S.S.
AT, HT	100-300	30-90	0.002-0.009	0.05-0.23	-	-	H.S.S.
Tapping							
A	50-100	15-30	-	-	-	-	H.S.S.
H	30-60	9-18	-	-	-	-	H.S.S.
AT, HT	15-25	5-8	-	-	-	-	H.S.S.
Alloys 3 and 10							
Turning							
All Tempers	1500-1800	450-550	0.010-0.025	0.25-0.64	0.050-0.125	1.27-3.18	C-2
Drilling							
A, H	200-600	60-180	0.002-0.005	0.05-0.13	-	-	H.S.S.
AT, HT	125-500	40-150	0.002-0.005	0.05-0.13	-	-	H.S.S.
Tapping*							
A	20-150	6-45	-	-	-	-	H.S.S.
H	10-60	3-18	-	-	-	-	H.S.S.
AT, HT	10-100	3-30	-	-	-	-	H.S.S.
BrushCAST® Alloys 275C, 245C, 20C, 21C and 165C							
Drilling							
C, A	100-250	30-75	0.002-0.005	0.05-0.13	-	-	H.S.S.
CT, AT	75-100	22-30	0.002-0.005	0.05-0.13	-	-	H.S.S.
Tapping							
C, A	20-50	6-15	-	-	-	-	H.S.S.
CT, AT	5-10	1-3	-	-	-	-	H.S.S.
Alloys 3C and 10C							
Drilling							
C, A	100-500	30-150	0.002-0.005	0.05-0.13	-	-	H.S.S.
CT, AT	75-200	22-60	0.002-0.005	0.05-0.13	-	-	H.S.S.
Tapping*							
C, A	10-75	3-22	-	-	-	-	H.S.S.
CT, AT	10-50	3-15	-	-	-	-	H.S.S.

NOTE: *Cutting speed is very critical when tapping Brush Alloys 3, 10, 3C and 10C. Cutting speed should be decreased as the size of the tap decreases.

The accompanying table recommends machining parameters for MoldMAX®, PROtherm™, ToughMet®, FormaMet®, and C18000 materials. These parameters are conservative values based on simple machining studies. Variations of these may be necessary depending on part geometry and available machine tools. Consult with Materion Brush Performance Alloys Technical Service for assistance developing custom parameters.

Recommended Speeds and Feeds for Machining Other Brush Performance Alloys Products

Operation	Cutting Speed		Feed Rate		Depth of Cut		Tool Material
	ft/min	m/min	in/rev	mm/rev	in	mm	
Alloys 25, M25 and 165							
Turning							
HH	900-1200	275-365	0.010-0.020	0.25-0.50	0.025-0.050	0.64-1.27	C-2
LH	1200-1500	365-450	0.010-0.020	0.25-0.50	0.025-0.050	0.64-1.27	C-2
V	900-1400	275-425	0.003-0.010	0.08-0.25	-	-	C-2
XL	1200-3000	365-900	0.010-0.020	0.25-0.50	-	-	C-2
PROtherm™	1500-2000	450-600	0.010-0.025	0.25-0.65	0.050-0.125	1.27-3.18	C-2
Drilling							
HH	100-300	30-90	0.002-0.009	0.05-0.23	-	-	Cobalt Steel
LH	100-400	30-125	0.002-0.009	0.05-0.23	-	-	Cobalt Steel
V	125-200	40-60	0.002-0.007	0.05-0.18	-	-	Cobalt Steel
XL	150-500	45-150	0.002-0.005	0.05-0.13	-	-	Cobalt Steel
PROtherm™	125-500	40-150	0.002-0.005	0.05-0.13	-	-	Cobalt Steel
ToughMet®							
Turning							
2 CX	300-3000	90-900	0.006-0.020	0.15-0.5	0.100	2.5	C-2
3 CX	400-800	120-240	0.005-0.012	0.13-0.3	0.100	2.5	C-5
3 AT	400-800	120-240	0.005-0.012	0.13-0.3	0.100	2.5	C-5
Drilling							
2 CX	300-3000	90-900	0.006-0.020	0.15-0.5			C-2
3 CX	150-500	45-150	0.005-0.020	0.13-0.5	-	-	C-5
3 AT	150-500	45-150	0.005-0.020	0.13-0.5	-	-	C-5
Tapping*							
2 CX	15	4.5	0.006-0.020	0.15-0.5	-	-	C-2
3 CX	10	3	0.005-0.020	0.13-0.5	-	-	C-5
3 AT	10	3	0.005-0.020	0.13-0.5	-	-	C-5
Other Alloys							
Turning							
FormaMet®	40-110	12-35	0.004-0.020	0.1-0.5	0.040-0.30	1-8	C-3
C18000	200-230	60-70	0.008-0.032	0.2-0.8	0.080-0.40	2-10	C-3
Drilling							
FormaMet®	20-40	6-13	0.002-0.004	0.06-0.1	-	-	C-3
C18000	20-36	6-11	0.002-0.004	0.06-0.1	-	-	C-3

Hardness

Although the tensile test is the official verification of mechanical properties, hardness is a useful approximation. Hardness testing is essentially nondestructive, it can be applied to finished components, and the equipment is reasonably portable. The hardness of a miniature contact, a resistance welding electrode or an aircraft bearing, for example, can be measured with a relatively simple test. Hardness correlates reasonably well with ultimate tensile strength in high performance copper alloys.

Each hardness test method has a minimum thickness limit to its applicability. Therefore, a test method must be selected with the gauge of the product in mind. The chart below lists hardness correlations for the test methods most commonly applied to copper beryllium.

A note of caution, however. Hardness values measured using one test method do not always correlate well with those from another. Where hardness is critical, as with stamped and age hardened parts, converted values should be avoided. For example, with a hardness specified as Rockwell C37 minimum, making a Rockwell 15N or 30N test and converting that to Rockwell C is less preferable than making the test on the Rockwell C scale directly. The conversions are useful when hardness is less critical, as it might be with inspection of incoming raw material. Hardness tests are best performed on flat surfaces, not on curved surfaces. If testing on a curved surface, please use the curvature adjustment procedures outlined in the relevant ASTM specification.

Diamond Pyramid and Vickers Hardness have the advantage that a continuous set of numbers covers the metallic hardness spectrum. This test allows hardness of products of different gauge to be compared directly. An important use of microhardness techniques is in measuring hardness of foils, fine wires and other products having small dimensions. Microhardness tests should be performed on a metallographically mounted cross section. They are generally not suited for surface hardness tests.

Minimum Thickness Requirements for Various Testing Methods

Rockwell Scales	Diamond Pyramid (DPH) or Vickers	Brinell
B and C - 0.040 in (1.0 mm) 30T and 30 N - 0.020 in (0.5 mm) 15T and 15 N - 0.015 in (0.38 mm)	- 0.002 in (0.05 mm)	- 0.125 in (3.2 mm)

Hardness Conversion Table[1]

Rockwell			Diamond Pyramid (DPH) or Vickers	Brinell	Rockwell			Diamond Pyramid (DPH) or Vickers	Knoop (HK)	Brinell
C	15N	30N		3000 kg	B	15T	30T			500 kg
48	84.5	66.5	485	460	100	93	82	240	251	201
47	84	66	471	448	99	92.5	81.5	234	246	195
46	83.5	65	458	437	98	–	81	228	241	189
45	83	64	445	426	97	92	80.5	222	236	184
44	82.5	63	435	415	96	–	80	216	231	179
43	82	62	424	404	95	91.5	79	210	226	175
42	81.5	61.5	413	393	94	–	78.5	205	221	171
41	81	60.5	403	382	93	91	78	200	216	167
40	80.5	59.5	393	372	92	90.5	77.5	195	211	163
39	80	58.5	383	362	91	–	77	190	206	160
38	79.5	57.5	373	352	90	90	76	185	201	157
37	79	56.5	363	342	89	89.5	75.5	180	196	154
36	78.5	56	353	332	88	–	75	176	192	151
35	78	55	343	322	87	89	74.5	172	188	148
34	77	54	334	313	86	88.5	74	169	184	145
33	76.5	53	325	325	85	–	73.5	165	180	142
32	76	52	317	317	84	88	73	162	176	140
31	75.5	51.5	309	309	83	87.5	72	159	173	137
30	75	50.5	301	301	82	–	71.5	156	170	135
29	74.5	49.5	293	293	81	87	71	153	167	133
28	74	48.5	285	270	80	86.5	70	150	164	130
27	73.5	47.5	278	265	79	–	69.5	147	161	128
26	72.5	47	271	260	78	86	69	144	158	126
25	72	46	264	255	77	85.5	68	141	155	124
24	71.5	45	257	250	76	–	67.5	139	152	122
23	71	44	251	245	75	85	67	137	150	120
22	70.5	43	246	240	74	–	66	135	147	118
21	70	42.5	241	235	73	84.5	65.4	132	145	116
20	69.5	41.5	236	230	72	84	65	130	143	114

NOTE: 1) Chart values based on ASTM E-140, Tables 1 and 2, for non-austenitic steels

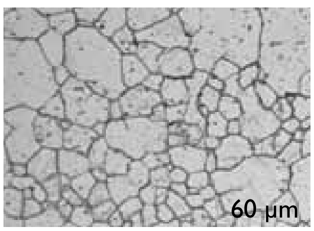
Microstructures

The combined effects of composition, cold work and thermal treatment are portrayed in the microstructure of each material.

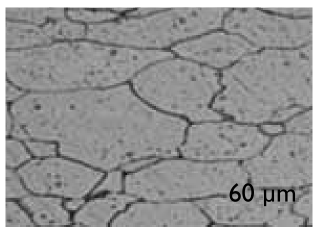
Copper Beryllium

Microstructural features are revealed on a metallographically prepared sample by etching with ammonium persulfate/ hydroxide or potassium dichromate. The former etchant delineates grain boundaries in all tempers and displays cold work effects in age hardened material. The latter etchant enhances the contrast of beryllides beyond the as-polished condition. Metallographic examination can thus be tailored to the processing conditions of the material.

Alloy 25 A

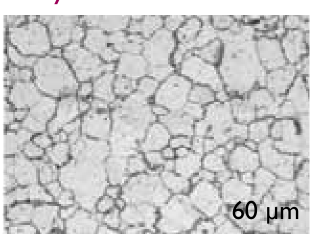


Alloy 25 H

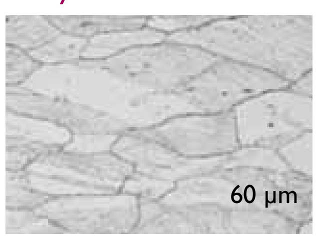


The microstructure of solution annealed Alloy 25 (A temper) reveals an equiaxed grain structure with uniformly dispersed cobalt beryllides. The H temper microstructure for Alloy 25 shows the effect of a cold rolling reduction of 37% of the original thickness on the grain structure. Cold working elongates the grain structure in the working direction.

Alloy 25 AT

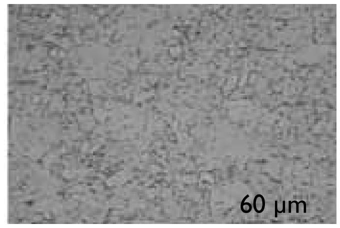


Alloy 25 HT

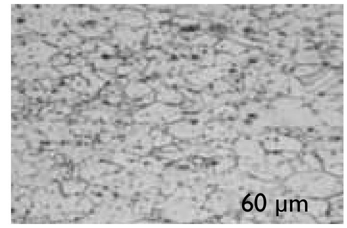


Alloy 25 in the AT temper shows a small amount of grain boundary precipitate in peak-aged product. Cold work plus age hardening produces the highest hardness and strength. The microstructure in the HT condition shows the effect of age hardening on cold worked Alloy 25. Standard age hardening does not change the grain size from that of annealed material. Precipitation of the strengthening gamma phase is not observable at this magnification.

Alloy 3 AT

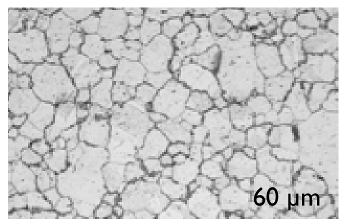


Alloy 3 HT

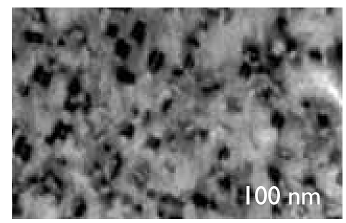


The high conductivity alloys are characterized in the A and AT tempers by equiaxed grains with a fine dispersion of nickel or cobalt rich beryllides. The microstructural features, in this case for Alloy 3, are somewhat more difficult to develop by etching.

Alloy 25 AT

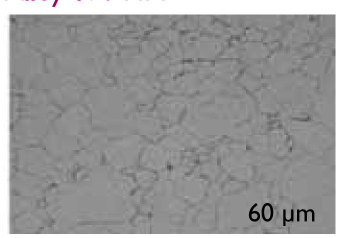


Alloy 25 TEM

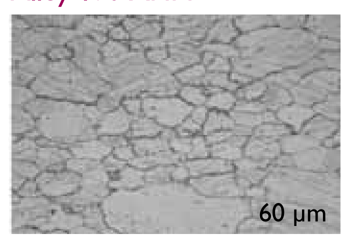


A bright field transmission electron micrograph (TEM) of Alloy 25 shows strain fields associated with precipitates. These precipitates are responsible for strengthening. They form initially as Guinier-Preston zones, pass through several stages of increasing tetragonality, ultimately ripening into the equilibrium gamma phase.

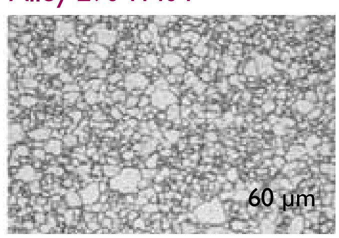
Alloy 190 HM



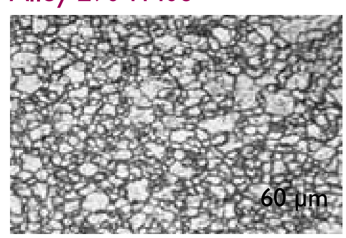
Alloy 190 XHM



Alloy 290 TM04



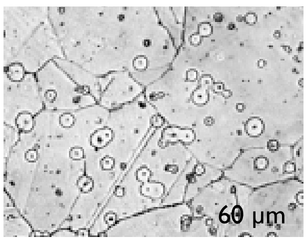
Alloy 290 TM06



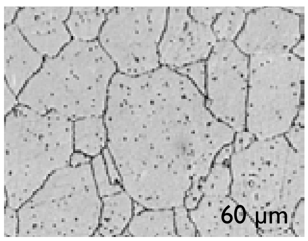
The microstructure of Alloy 190 is similar to that of peak aged Alloy 25. The higher strength tempers are more heavily cold worked prior to mill hardening. Some grain boundary precipitate is visible. The 290 alloys show a more equiaxed microstructure with a finer grain size than the 190 Alloys.

Photomicrographs of Alloys M25 and 25 are shown below for comparison. The presence of lead in M25 is made visible through special metallographic preparation. The lead is uniformly dispersed and appears as fine particles inside circles which are artifacts of the special etching process. Although the presence of lead limits hot working, it does not affect the response to age hardening, which is identical to that of Alloy 25.

Alloy M25 AT



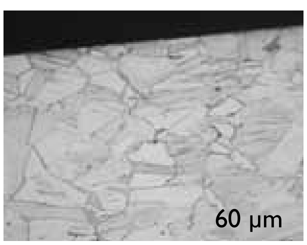
Alloy 25 AT



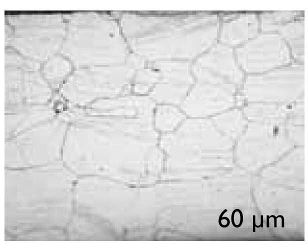
Other Alloys

The microstructures of BrushForm® 158 and ToughMet® alloys are best revealed by using an etchant of potassium dichromate, sulfuric acid and hydrochloric acid. The ammonium persulfate/ ammonium hydroxide etch used for copper beryllium also will work.

BrushForm® 158 A

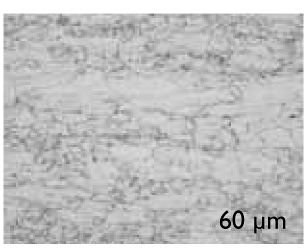


BrushForm® 158 HT

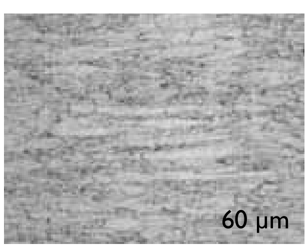


The heat treatable and heat treated microstructures of the BrushForm® 158 material are very similar to that of copper beryllium.

BrushForm® 158 TM04



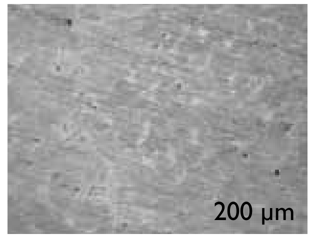
BrushForm® 158 TM08



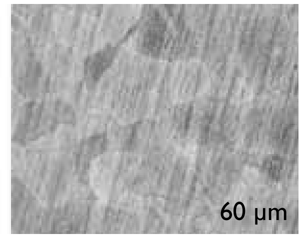
The mill hardened tempers of BrushForm® 158 show microstructures similar to that of the peak aged HT temper.

ToughMet®

ToughMet® 3 CX105

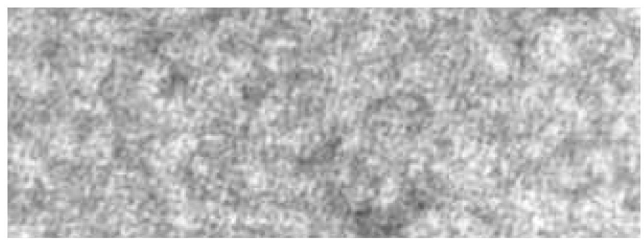


ToughMet® 3 AT110



ToughMet® 3 AT is very similar to BrushForm® 158 AT. The CX tempers show a more duplexed microstructure consistent with a cast and aged alloy.

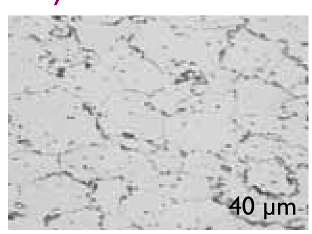
ToughMet® Tin Spinodal
Nanostructure TEM-160,000X



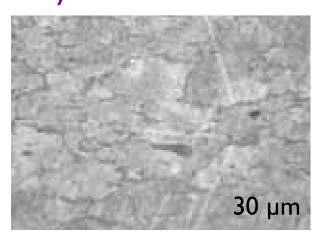
A Transmission Electron Micrograph (TEM) image of ToughMet® 3 shows the alternating waves of chemically different but structurally coherent atomic clusters of tin present after spinodal decomposition.

Nickel Beryllium

Alloy 360 ½ HT

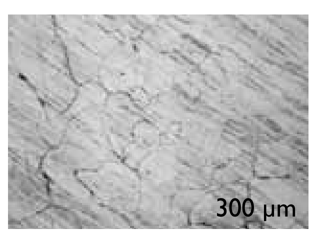


Alloy 360 MH06

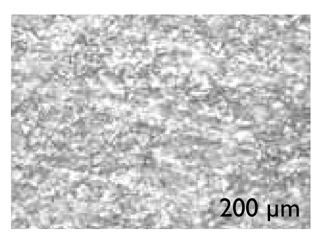


Nickel Beryllium has a similar microstructure to Alloy 25. Its microstructure can be revealed by etching with either Marble's etchant or nitric acid and water.

MoldMAX® XL



MoldMAX® V



MoldMAX® XL has a microstructure similar to that of the ToughMet® 3 material, since it is spinodally hardened after casting. MoldMAX® V is a precipitation hardened alloy. Its microstructure will contain a large number of nickel silicide particles.

Other Attributes and Application Engineering Data

Materion Brush Performance Alloys are used because they provide a combination of attributes meeting specific needs of a user's application. Examples include elastic compliance and formability (electronic connector contacts), fatigue strength and electrical conductivity (switch contacts), hardness and thermal conductivity (resistance welding electrodes), and wear and galling resistance (bushings and bearings).

Copper beryllium and copper nickel tin have many more useful attributes of which the designer should be aware. Several are highlighted in this section.

Fatigue Strength

Copper beryllium strip and wire have a long history of success in the cyclic stress environment of electrical and electronic contact springs. Copper beryllium in heavier sections also is used in components subject to cyclic loading. Examples include aircraft landing gear bushings, races and rollers in rolling-element bearings, and oil and gas well downhole drilling and measurement tools.

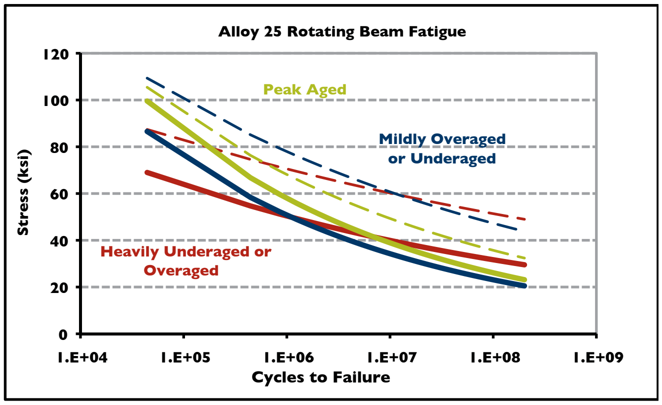
In these applications an outstanding characteristic of copper beryllium and copper nickel tin is their ability to withstand cyclic stress. Cyclic conditions are produced by cantilever bending, axial loading and rotational bending.

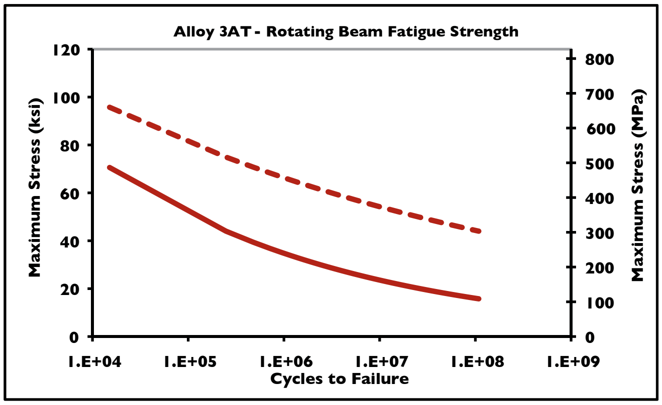
Fatigue strength is defined as the maximum stress that can be endured for a specified number of cycles without failure. Low cycle fatigue strength approaches the static strength. Unlike steels, copper alloys show a continuously falling S-N curve. Copper beryllium and copper nickel tin alloys resist fatigue failure with high static strength, toughness and an ability to diffuse strain by work hardening.

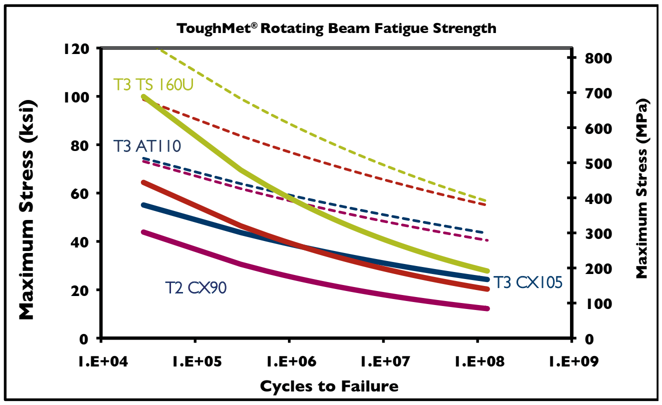
Copper beryllium and copper nickel tin fatigue curves are provided in the graphs on the next two pages. The ratio of minimum to maximum stress is termed the stress ratio, "R". This term, displayed on the graphs, defines the test conditions. Spring contacts deflected in a single direction (R = 0) display a higher fatigue strength than those flexed in reverse bending (R = -1). Rod also is measured in fully reversed (R = -1) rotating beam tests.

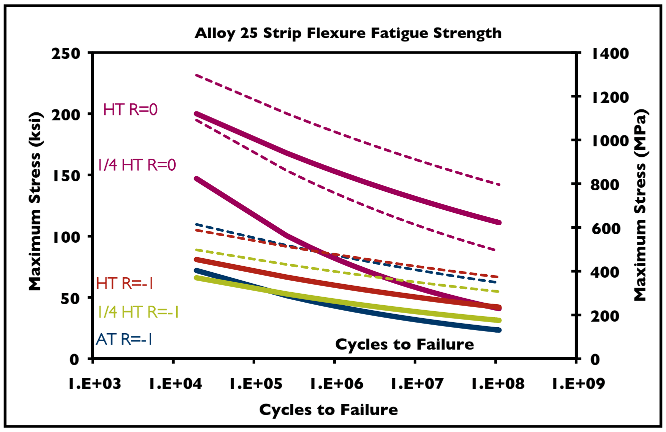
Standard tests measure fatigue behavior of flat springs and round beams. Some spring manufacturers have developed their own tests to suit their particular design requirements. Agreement among testing methods is generally good.

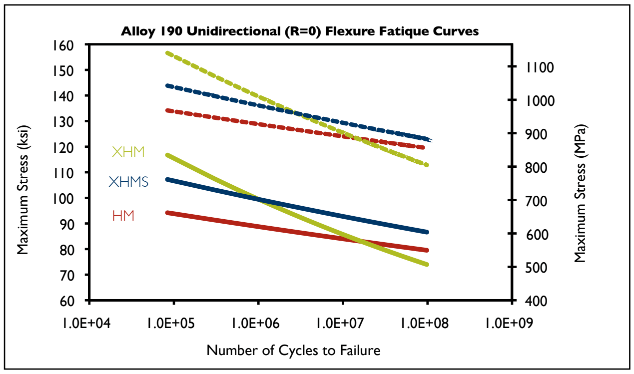
All curves shown on these pages are for testing in the longitudinal direction, unless otherwise specified. These charts serve as a guide, since fatigue performance depends on the surface condition and service stress state. Care should be taken to insure high surface quality, particularly at edges and fillet radii, to take maximum advantage of these important alloys. Furthermore, the curves represent a best fit of scattered data, with the solid colored curves representing the bottom of the scatter band and the dashed curves representing the top of the scatter band.

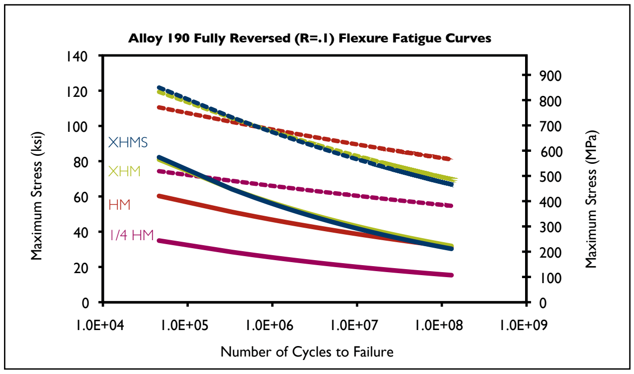


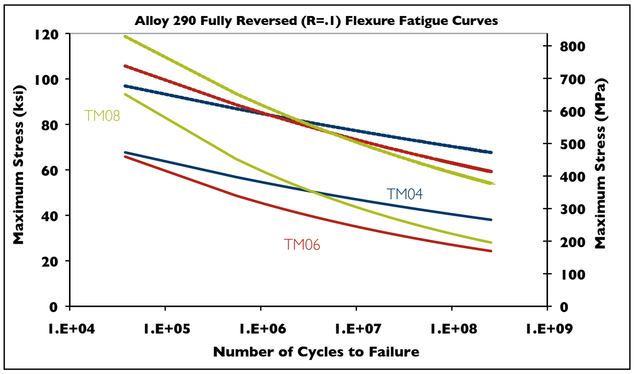


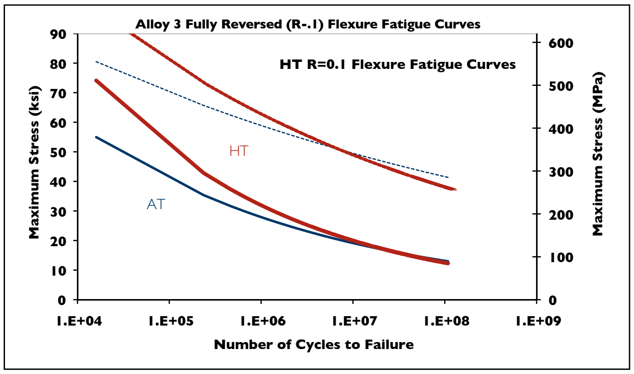


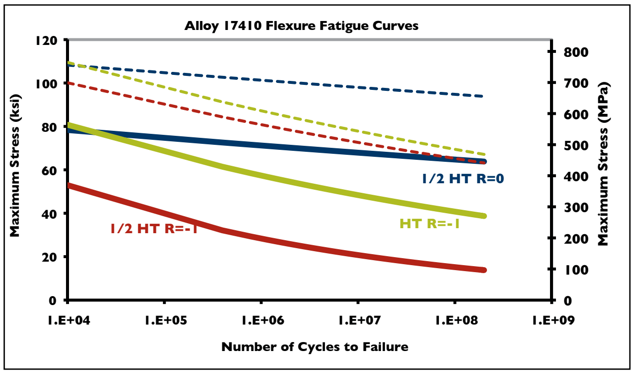


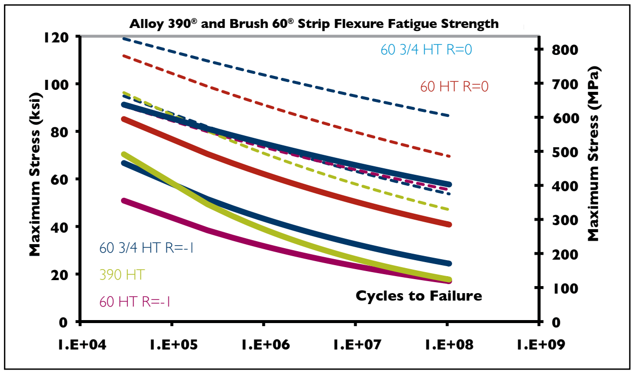

Alloy 190 Unidirectional (R=0) Flexure Fatique Curves
XHM
XHMS
HM
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure

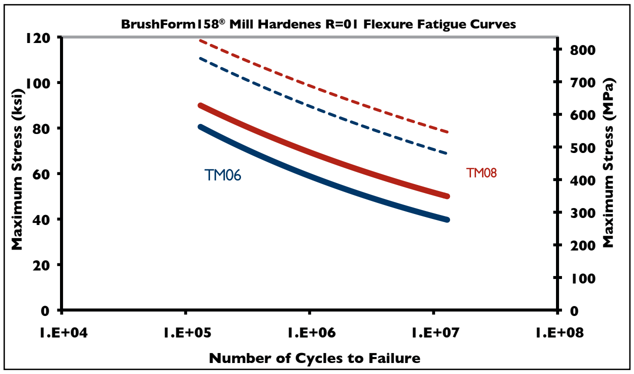

Alloy 190 Fully Reversed (R=.1) Flexure Fatigue Curves
XHMS
XHM
HM
1/4 HM
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure

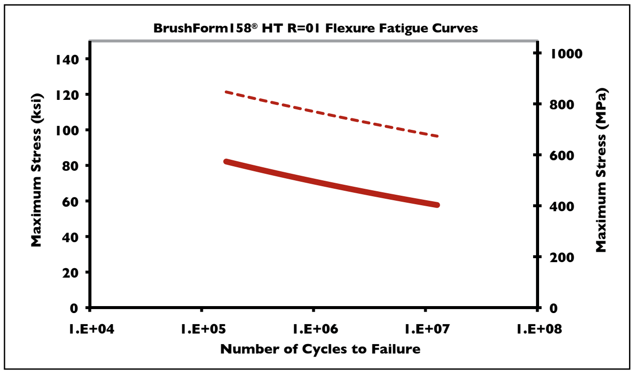

Alloy 290 Fully Reversed (R=.1) Flexure Fatigue Curves
TM08
TM04
TM06
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure


Alloy 3 Fully Reversed (R-.1) Flexure Fatigue Curves
HT R=0.1 Flexure Fatigue Curves
HT
AT
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure


Alloy 17410 Flexure Fatigue Curves
1/2 HT R=0
HT R=-1
1/2 HT R=-1
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure


Alloy 390® and Brush 60® Strip Flexure Fatigue Strength
60 3/4 HT R=0
60 HT R=0
60 3/4 HT R=-1
390 HT
60 HT R=-1
Cycles to Failure
Maximum Stress (ksi)
Maximum Stress (MPa)


BrushForm158® Mill Hardenes R=01 Flexure Fatigue Curves
TM06
TM08
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure


BrushForm158® HT R=01 Flexure Fatigue Curves
Maximum Stress (ksi)
Maximum Stress (MPa)
Number of Cycles to Failure

Stress Relaxation Resistance

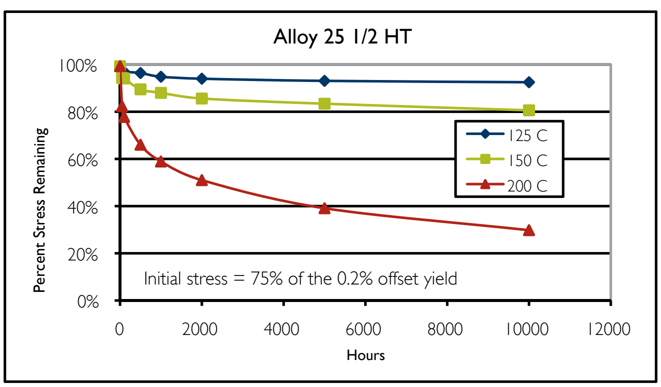
Copper beryllium alloys are often chosen because of their inherent resistance to stress relaxation. Miniaturization in computer hardware, automotive interconnections and aerospace systems has accented the importance of high thermal stability. Today, many electronic contacts and other spring elements must remain stable longer while operating at higher temperatures more than ever before.

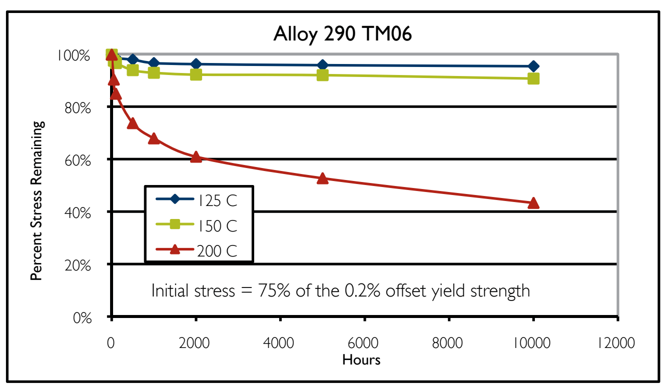
Stress relaxation is commonly evaluated on samples cut from strip and subjected to constant elastic bending strain at moderately elevated temperature. In one common method, a sample is secured in a fixture and deflected as a cantilever beam to an initial stress that is a predetermined fraction of the alloy's 0.2% offset yield strength, typically 75%. The fixture and deflected sample are exposed to high temperature for extended time, usually up to 1,000 hours. Stress relaxation causes permanent set. The ratio of permanent set to initial deflection defines the degree of loss of initial bending stress caused by relaxation.

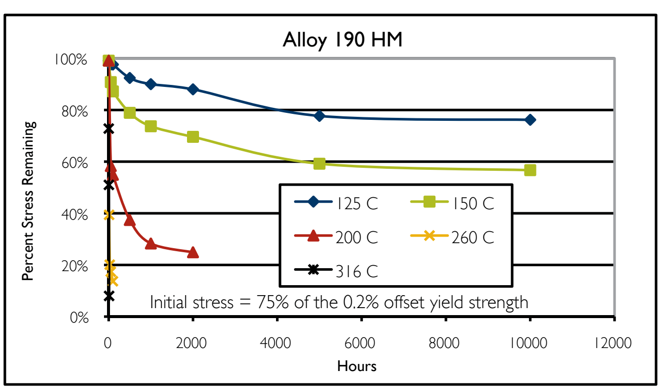
The stress relaxation behavior of several alloys is displayed in the figures on this page. The most commonly used temper has been selected for each alloy. Isothermal charts are used in this instance. This means that each chart contains a single material, and that the remaining stress for a given temperature is shown as a continuous line.

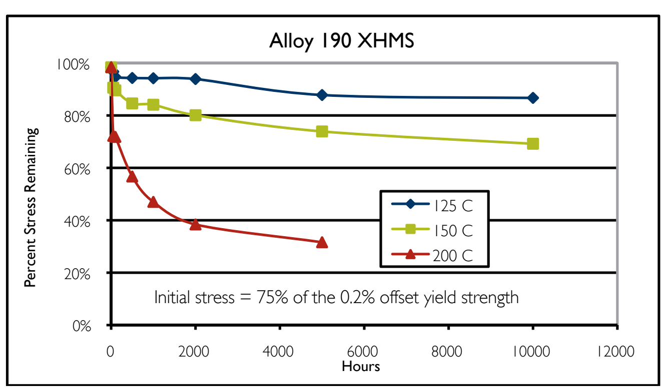
All of the alloys have been tested to a minimum of 1,000 hours, although some have been tested up to 10,000 hours. Please note the time scale on the axis when reading the charts. The copper beryllium alloys have a vertical axis starting at 0% stress remaining and ending at 100% stress remaining. However, the stress relaxation behavior of the nickel beryllium alloy is substantially better, so the vertical axis starts at a 70% for the age hardened tempers and at 90% for the mill hardened tempers.

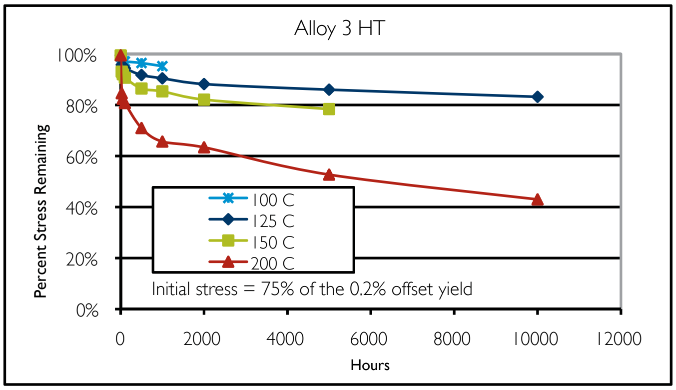
The low temperature stress relaxation resistance of the mill hardened tempers of BrushForm® 158 is equivalent to that of Alloy 290, while that of the treatable tempers is equivalent to Alloy 25. BrushForm® 158 will exhibit superior performance at higher temperatures.

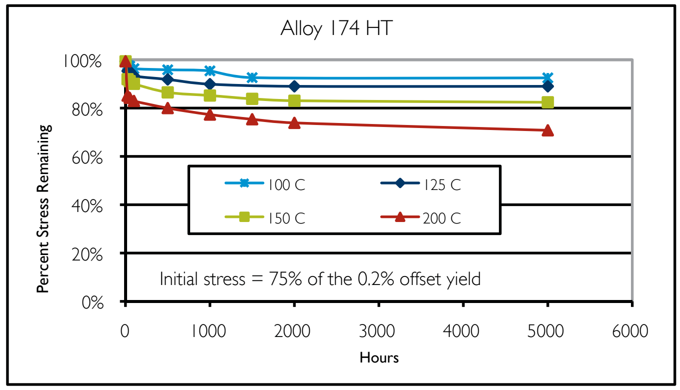


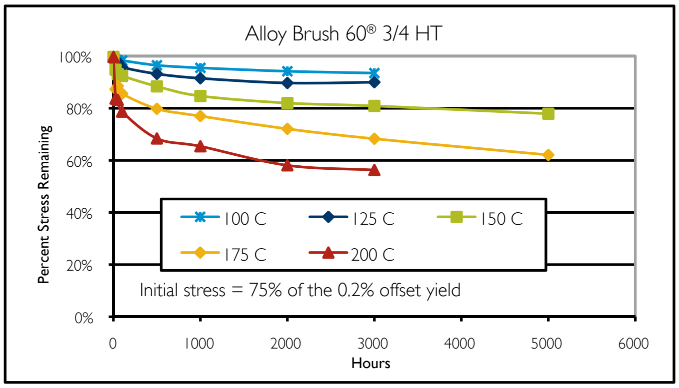


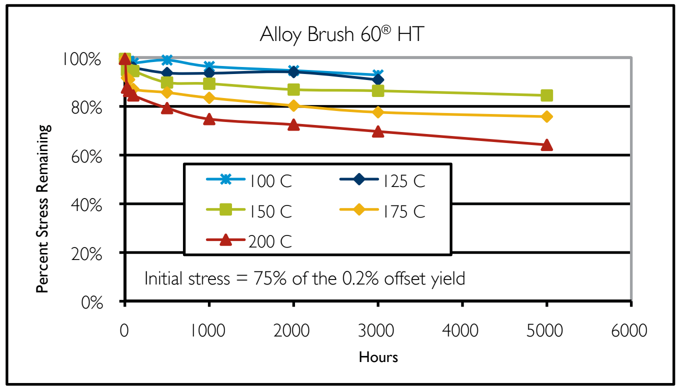


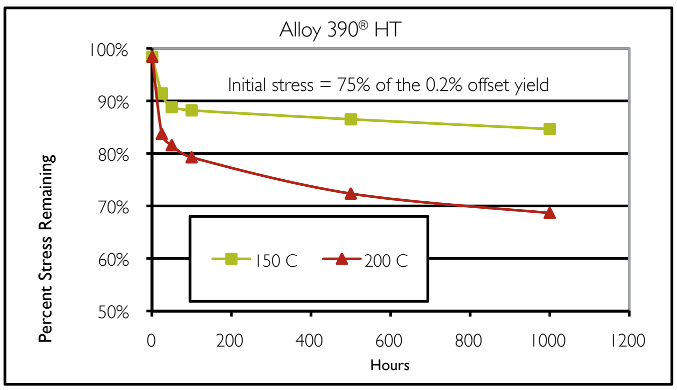


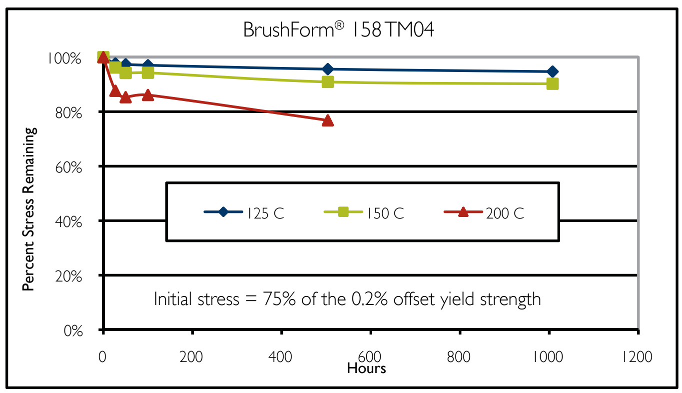

Alloy 3 HT
Percent Stress Remaining
100%
80%
60%
40%
20%
0%
0
2000
4000
6000
8000
10000
12000
Hours
100 C
125 C
150 C
200 C
Initial stress = 75% of the 0.2% offset yield

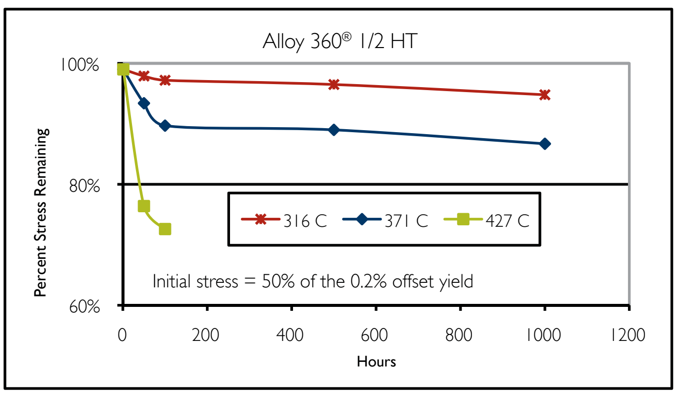

Alloy 174 HT
Percent Stress Remaining
100%
80%
60%
40%
20%
0%
0
1000
2000
3000
4000
5000
6000
Hours
100 C
125 C
150 C
200 C
Initial stress = 75% of the 0.2% offset yield

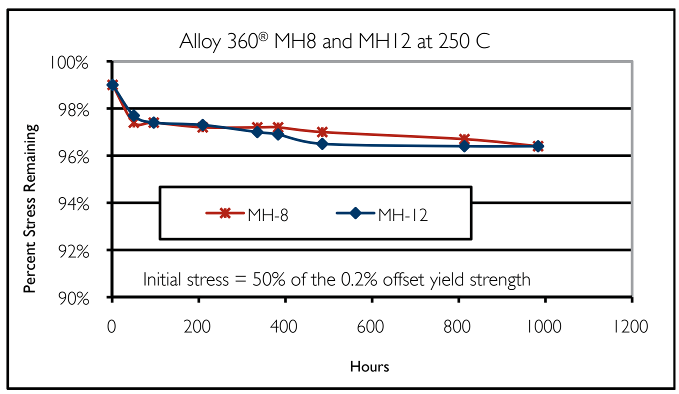

Alloy Brush 60® 3/4 HT
Percent Stress Remaining
100%
80%
60%
40%
20%
0%
0
1000
2000
3000
4000
5000
6000
Hours
100 C
125 C
150 C
175 C
200 C
Initial stress = 75% of the 0.2% offset yield


Alloy Brush 60® HT
Percent Stress Remaining
100%
80%
60%
40%
20%
0%
0
1000
2000
3000
4000
5000
6000
Hours
100 C
125 C
150 C
175 C
200 C
Initial stress = 75% of the 0.2% offset yield


Alloy 390® HT
Percent Stress Remaining
100%
90%
80%
70%
60%
50%
0
200
400
600
800
1000
1200
Hours
Initial stress = 75% of the 0.2% offset yield
150 C
200 C


BrushForm® 158 TM04
Percent Stress Remaining
100%
80%
60%
40%
20%
0%
0
200
400
600
800
1000
1200
Hours
125 C
150 C
200 C
Initial stress = 75% of the 0.2% offset yield strength


Alloy 360® 1/2 HT
Percent Stress Remaining
100%
80%
60%
0
200
400
600
800
1000
1200
Hours
316 C
371 C
427 C
Initial stress = 50% of the 0.2% offset yield


Alloy 360® MH8 and MH12 at 250 C
Percent Stress Remaining
100%
98%
96%
94%
92%
90%
0
200
400
600
800
1000
1200
Hours
MH-8
MH-12
Initial stress = 50% of the 0.2% offset yield strength

Corrosion Resistance

Atmospheric Tarnish Resistance and Shelf Life

In environments encountered during production, storage, and use of electronic or electrical apparatus, copper beryllium alloys exceed the corrosion resistance of most specialty copper alloys. Resistance to tarnish is critical since many electronic components are soldered after extended storage. Surface inhibition with benzotriazole (BTA) reduces oxide formation and extends shelf life. For optimum solderability, copper beryllium may be coated with tin prior to storage. Please contact the Technical Service department for additional information.

Copper Beryllium

Glycols, alcohols, esters, ketones, hydrocarbons and most organic solvents are routinely handled with copper beryllium. The sensitivity of copper beryllium to impurities contained in these liquids is usually greater than sensitivity to the organic itself. For example, traces of sulfides, water, acids, alkalis or salts may accelerate corrosion.

Curing polyvinyl chloride (PVC) and room temperature vulcanized silicone (RTV) plastics can produce fumes, such as hydrochloric and acetic acid, that can corrode copper beryllium and other copper based alloys. However, copper beryllium is used successfully in these applications by limiting the production of these corroding fumes. The curing of other plastics, such as acetal, nylon and polytetrafluoroethylene (PTFE), emits volatiles under similar conditions, but these fumes do not affect copper alloys.

Copper beryllium alloys are compatible with aqueous solutions of most alkali hydroxides, hot or cold. However, many copper alloys, including copper beryllium, are not suitable for handling ammonium hydroxide, which promotes stress corrosion cracking. Copper beryllium alloys should not be in contact with ammonia unless it is dry and oxygen free.

The alloys resist corrosion in cold concentrated sulfuric acid; hot or cold dilute sulfuric acid; hydrofluoric acid; or cold dilute hydrochloric acid. However, like other copper alloys, copper beryllium is not recommended for structural components that are exposed to concentrated oxidizing acids such as nitric. Non-oxidizing acids such as hydrochloric and sulfuric are corrosive when they contain oxidizing impurities.

Copper beryllium is immune to stress corrosion cracking caused by chloride ions, unlike stainless steel that can crack in just a few hours under high chloride conditions. This immunity makes copper beryllium ideal for applications in oil well environments. Copper beryllium resists hydrogen embrittlement unlike titanium alloys, steels and nickel base alloys that are highly susceptible, at comparable strength.

Copper beryllium is susceptible to delayed failure by liquid metal embrittlement by mercury. Strengthening by either cold working or age hardening increases this susceptibility.

Copper Beryllium Service Environments:

- **Industrial** – shelf life sufficient for solderability to 18 months
- **Urban** – sulfidation resistance up to five times that of copper
- **Static Sea Water** – less than 2 mils per year
- **Biofouling** – proven resistance, with more than thirty years exposure
- **Saturated Chlorides** – immune to cracking in sodium, potassium, magnesium and mixed salts
- **Hydrogen** – no effect on ductility or strength after cathodic charging at 90°F for more than 100 hours
- **Organics** – compatible with most solvents, although impurities may cause corrosion
- **Organic Fumes** – resistance should be evaluated case by case
- **Dilute Acids and Alkalis** – may be used with caution
- **Concentrated Oxidizing Acids** – not recommended for use
- **Ammonia** – resistant to attack by anhydrous ammonia, but presence of moisture and oxygen promote stress corrosion cracking
- **Mercury and Other Liquid Metals** – avoid contact
- **Other** – attacked by ferric chloride, ferric sulfide, acid chromates, ammonium hydroxide and mercury compounds

ToughMet®

ToughMet® 3 is resistant to stress corrosion cracking and hydrogen embrittlement in synthetic seawater slow strain rate testing. There was no reduction of load carrying capability or change in failure mode under all conditions, including freely corroding and various galvanic coupling situations. Low corrosion rates were observed, similar to other copper nickel alloys. No pitting corrosion was observed. ToughMet® 3 is galvanically similar to other copper-nickel alloys.

The ToughMet 3® TS tempers possess nearly the same level of corrosion resistance that the CX and AT tempers do.

ToughMet® 3 complies with NACE MR0175 and ISO 15156 standards for unrestricted Sour Well Service per Section 4 including notations (tested up to 150 C˚ NACE Level V). NACE standard testing indicates that ToughMet® 3 shows resistance to amine-based fluid corrosion (no embrittlement or accelerated weight loss). It is resistant to seawater and brine corrosion, with a general corrosion rate less than 0.001" per year and no susceptibility to hydrogen embrittlement, including notched areas. No pitting or corrosion cracking occurred when tested in high concentrations of chlorides or bromides. It is resistant to biofouling, and ammonia stress cracking. When pre-stressed to 90% of its yield strength for 30 days immersion in NACE Levels I, IV and V test solutions, it shows a minimal general corrosion rate (1-3 mil per year) and no sulfide stress corrosion cracking.

Nickel Beryllium

Alloy 360 nickel beryllium shows the same outstanding corrosion resistance as Nickel 200 or Nickel 201. Resistance to stress corrosion cracking is characteristic of many high nickel alloys. Alloy 360, is highly resistant to caustic, chloride and hydrogen sulfide stress corrosion cracking and also is resistant to stress corrosion cracking in ammonium hydroxide and ammonia.

Corrosion Data

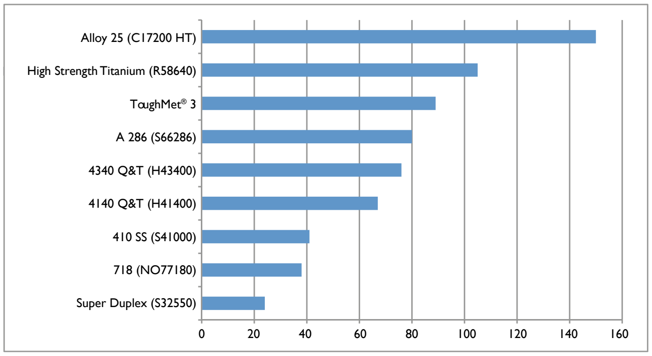
Immunity to Hydrogen embrittlement – Copper beryllium and ToughMet® alloys are not susceptible to hydrogen embrittlement, as seen in the chart on the right. Most steel and nickel alloys will show susceptibility to hydrogen embrittlement.

Marine Environments

Copper beryllium, copper nickel tin and cupronickel alloys are well suited for both fresh and salt water because of a low corrosion rate and an inherent resistance to biofouling. At low velocity, the corrosion rate of copper beryllium in sea water is low and comparable to the cupronickels. Copper nickel tin shows even greater corrosion resistance. High velocity accelerates corrosion of copper beryllium and most copper alloys. Undersea communication cable housings have seen more than thirty years of undersea service without evidence of fouling or detrimental corrosion. These are made from copper beryllium because of its excellent strength, machinability and resistance to corrosion and fouling.

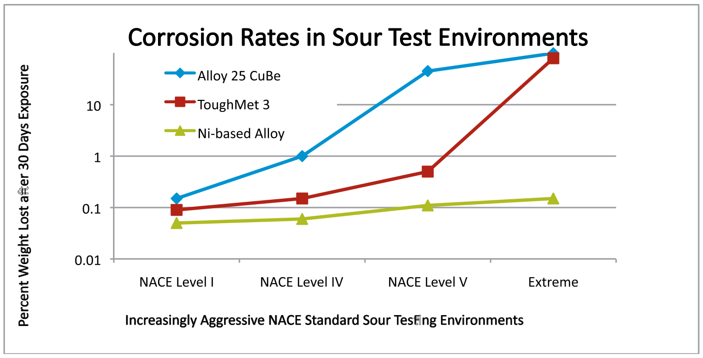
Resistance to Hydrogen Embrittlement of Various Materials as Indicated by Slow Strain Rate Tensile Testing

After 8 Day Cathodic Charging in Aerated Seawater



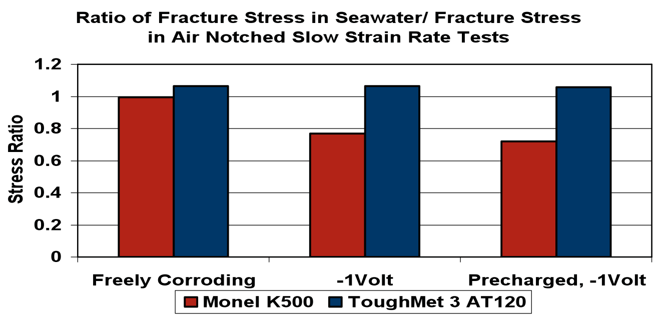
% Ductility Remaining (RA envir/RA inert)

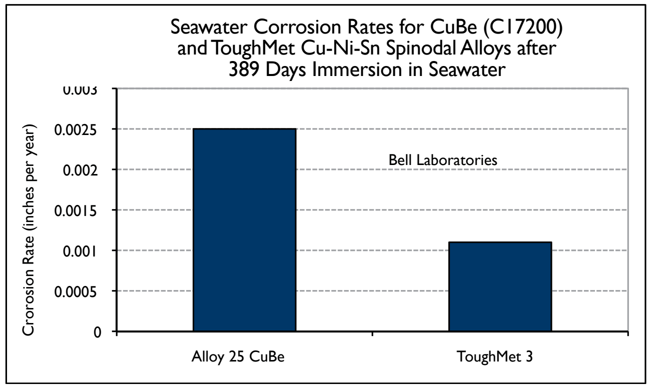
Source: Conoco and Cameron



Cathodic Protection

ToughMet® was tested to examine the alloy's response in cathodically protected situations in seawater. The results of these tests show that ToughMet® is unaffected by either seawater exposure or hydrogen embrittlement.

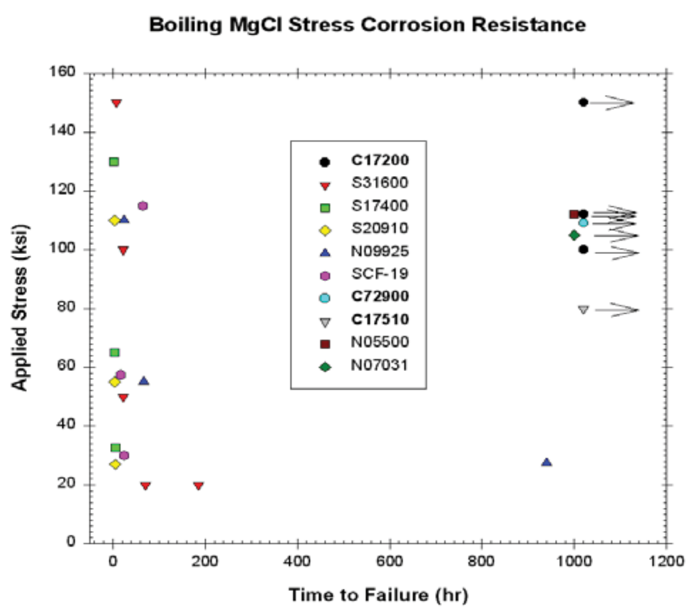




For additional information, please see the following: J. O. Ratka and M. N. Maligas "Corrosion Evaluation of a High Performance Cu-Based Alloy for Seawater Applications", CORROSION 2004, Paper No. 04298, NACE International, 2004.

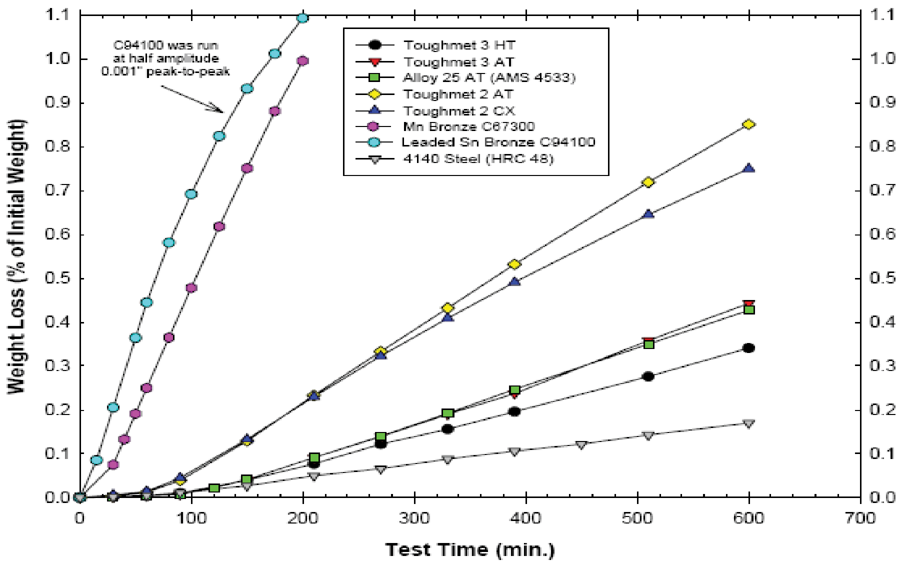
Chloride Stress Corrosion Cracking Resistance

A method of commonly evaluating material susceptibility to Chloride SCC is ASTM Standard Practice G 36, "Performing Stress-Corrosion Cracking in a Boiling Magnesium Chloride Solution." This accelerated test method incorporates C-ring specimens exposed to the solution for 1000 hrs or failure. The specimens were loaded to an applied stress of 100% of the yield strength. ToughMet® 3AT (C72900) and copper beryllium Alloy 25 (C17200) experienced no failure in these tests. The results are shown on the right. See Materion Brush Performance Alloys Tech Brief "Chloride Stress Corrosion" for more information.



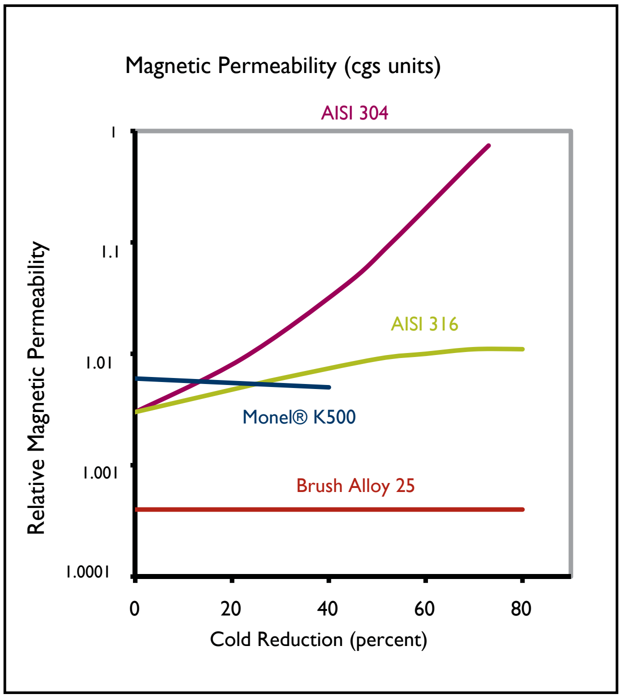
Cavitation Erosion Resistance

The results below were obtained per ASTM G 32, "Cavitation Erosion Using Vibratory Apparatus," which subjects a metal to cavitation in deionized water. This method is often used as a screening test to compare metal erosion from cavitation damage in a controlled environment. External factors such as dissolved or suspended particles, galvanic effects or corrosive environments are not covered by this test and should be treated as application specific. The results of this test indicate the relative wear from turbulent fluid flow as might be experienced in pumps and lubricated applications with high shear rate. See Brush Performance Alloys Tech Brief " Cavitation Resistance of Selected Copper Alloys" for more information.



Magnetic Properties

Brush Alloy 25 has magnetic permeability between 0.997 and 1.001 at a field strength of 1000 gauss. (A permeability of unity represents perfect transparency to slowly varying magnetic fields.) ToughMet® 2 and ToughMet® 3 has a similar magnetic permeability, less than 1.001. This property is unaffected by cold work in contrast to other nonmagnetic alloys that can become magnetically "hot" during machining, forming or rigorous service. Combined with high strength, fracture toughness and precise dimensional stability, these properties lead to excellent service in magnetic instrument housings, magnetic support structures and other systems.



Galling Resistance

Copper beryllium and ToughMet® 3 have inherently good resistance to galling and wear, allowing contact with other materials with a minimum of friction and surface damage. Threaded joints of copper beryllium mated to itself or to stainless steel are not subject to galling, even under overload conditions.

Alloy 25 Galling Tests per ASTM G 98

Button on Block Testing

	Test Material Run against Alloy 25 AT	Test Material Yield Strength		Threshold Galling Stress	
		ksi	MPa	ksi	MPa
Stainless Steel	304	55	379	30 +	207 +
	316	44	303	30 +	207 +
	416	92	634	70 +	483 +
	440C	79	545	50 +	345 +
	Nitronic® 50	79	545	60 +	414 +
	Nitronic® 60	56	386	55 +	379 +
	Alloy 2205	87	600	80 +	552 +
	Carpenter 20Cb-3	72	496	40 +	276 +
	15-5 PH	149	1027	90 +	621 +
	17-4 PH	146	1007	90 +	621 +
	Custom 455	132	910	60 +	414 +
	Gall-Tough®	65	448	50 +	345 +
Nonferrous Alloys	Inconel® 600	106	731	30	207
	Inconel® 625	85	586	5	34
	Inconel® 718	83	572	< 3.7	< 26
	Monel® 400	82	565	< 30	< 207
	Monel® K500	115	793	50 +	345 +
	Nickel 200	69	476	2.5	17
	Waspaloy®	85	586	< 2.5	< 17
	MP35N®	145	1000	75 +	517 +
Steel	1018	85	586	< 10	< 69
	4140	142	979	< 10	< 69
	4340	157	1082	< 20	< 138
	8620	98	676	50 +	345 +
	300 M	106	731	60 +	414 +
Light Metals	Al 1100	23	159	7.5	52
	Al 6061 T6	53	365	< 2.5	< 17
	Al 7075 T6	77	531	< 2.5	< 17
	Titanium CP Grade 2 Annealed	53	365	< 2.5	< 17
	Ti-6Al-4V	142	979	7.5	52

+ Symbol Indicates No Galling at Applied Stress Level

ToughMet® 3 AT110 Galling Test per ASTM G 98

Button on Block Testing

Test Material Run against T3 AT110	Hardness of Test Material	Applied Stress		Test Remarks
		ksi	MPa	
Allvac® 718	HRC 39.6	93.9	647	No Galling
		104.5	721	Button Deformed, No Galling
Nitronic® 50	HRC 33.3	42.2	291	No Galling
		47.9	330	Galling/Deformed
MP35N®	HRC 45.2	98.7	681	No Galling
		109.6	756	Slight Galling
304 Stainless Steel	HRC 28.9	< 69.5	< 479	Galling/Deformed
				(no lower stress applied)
Ti-6Al-4V	HRC 36.9	47.4	327	No Galling-Galling
		52.6	363	Galling
K500 Monel®	HRC 35.7	52.4	361	No Galling
		57.7	398	Galling
Custom 630 (17-4 PH Stainless Steel)	HRC 35.7	70.2	484	No Galling
		81.6	563	Galling
15-5 PH Stainless Steel	HRC 35.6	76.4	527	No Galling
		81.5	562	Galling
Inconel® 625	HRC 27.9	63.6	439	No Galling
		66.2	456	Slight Galling
		71.3	492	Galling
440C Stainless Steel	Heat Treated to HRC 59	92.2	636	No Galling
		98.6	680	Galling
4340 Steel	Heat Treated to HRC 28	67.5	465	No Galling
		75.3	519	Galling
4340 Steel	Heat Treated to HRC 45	88.6	611	No Galling
		94	648	Galling
T3 AT110 (Self-Mated)	HRC 30	79.9	551	No Galling
		86.2	594	Galling

Allvac® is a registered trademark of ATI Properties Inc.
Nitronic® is a registered trademark of AK Steel Corp.
MP35N® is a registered trademark of Pratt & Whitney Aircraft
Inconel® and Monel® is a registered trademark of Special Metals Corp.
Gall-Tough® is a registered trademark of Carpenter Technology Corp.

Bearing Properties

Both copper beryllium and ToughMet® possess an intriguing array of properties that lead them to use in heavy-duty wear plate, bushing and bearing applications such as aircraft landing gear, heavy equipment in mining and manufacturing, industrial presses, etc.

Compressive Strength and Shear Strength

The compressive and shear strength values of copper beryllium and ToughMet® are shown in the data tables below. The compressive strength exceeds the yield strength in tension for these product forms.

Please see the Materion Brush Performance Alloys Tech Brief "Anti-Friction Behavior of Selected Copper-Based Bearing Alloys," for more information.

Pin Bearing Ultimate Strength[1]

	e/D = 1.5		e/D = 2.0	
	ksi	MPa	ksi	MPa
ToughMet® 3 AT110	180 - 210	1241 - 1448	235 - 270	1620 - 1862
ToughMet® 3 TS160U	200 - 211	1379 - 1455	240 - 278	1655 - 1917
Alloy 25	235 - 242	1620 - 1669	298 - 306	2055 - 1110
Alloy 25 AT	220 - 230	1516 - 1585	280 - 300	1931 - 2068
Alloy 25 HT	231 - 250	1593- 1724	293 - 317	2020 - 2186

Compressive Strength and Modulus Values

	Yield Strength		Elastic Modulus	
	ksi	MPa	Mpsi	GPa
ToughMet® 3 AT110	119 - 125	820 - 862	20.5	141
ToughMet® 3 TS160U	140 - 155	965 - 1041	21.3	147
Alloy 25 H	140 - 160	965 - 1103	18.7	129
Alloy 25 AT	139 - 150	958 - 1034	18.7	129
Alloy 25 HT	148 - 157	1020 - 1082	18.7	129

Pin Bearing Yield Strength[1]

	e/D = 1.5		e/D = 2.0	
	ksi	MPa	Mpsi	GPa
ToughMet® 3 AT110	159 - 169	1096 - 1165	190 - 199	1310 - 1372
ToughMet® 3 TS160U	184 - 193	1269 - 1331	206 - 224	1420 - 1544
Alloy 25	205 - 210	1413 - 1447	220 - 230	1516 - 1586
Alloy 25 AT	195 - 205	1344 - 1413	220 - 230	1516 - 1586
Alloy 25 HT	207 - 230	1427 - 1586	225 - 251	1551 - 1731

Shear Strength and Modulus Values

	Shear Strength		Shear Modulus	
	ksi	MPa	Mpsi	GPa
ToughMet® 3 AT110	86 - 89	593 - 614	-	-
ToughMet® 3 TS160U	88 - 93	607 - 641	8.0	55
Alloy 25	89 - 93	614 - 641	7.3	50
Alloy 25 AT	90 - 100	621 - 689	7.3	50
Alloy 25 HT	90 - 100	621 - 689	7.3	50

NOTE: 1) Strength varies by rod size. Smaller diameters typically have the higher strength. Consult MMPDS handbook for statistically derived design allowables.

Friction & Wear Properties

Low Friction

In any application involving sliding surfaces it is important to understand that no single material property of a fabric governs the frictional response. For example, low coefficient of friction may not guarantee success in a design which relies on only modest sections for assembly support -- high strength also may be needed to fulfill this support need. For example, this might be the case for a bronze shaft operating against a steel segment on rotating machinery, where the shaft is heavily loaded in bending. Generally, designs undoubtedly command freedom from galling and seizing early in the life cycle, so good friction characteristics (i.e. low coefficient of friction) are desirable. ToughMet® has an extremely uniform microstructure, without small inclusions of harder phases that tend to increase friction in most other alloys.

PV Limit Comparisons

Material (Lubricated, except where noted)	Maximum PV (psi-sfpm)
ToughMet® 3	275,000
Manganese Bronze	150,000
Aluminum Bronze Cast	125,000
C93200 75,000	75,000
SAE 841 Bronze PM	50,000
SAE 863 Fe PM	35,000
60 Cu 40 Fe	35,000
PM SAE 850 Fe	30,000
High Sn Babbitt (89%)	30,000
Low Sn Babbitt (10%)	18,000
ToughMet ® 3 Unlubricated	17,000
Graphite/Metallized Bearings	15,000
Carbon	15,000
Low Sn Low Pb (6%) Babbitt	12,000

Table 2. PV imit comparison data from Bunting Bearing Corp.

Resilience and Toughness

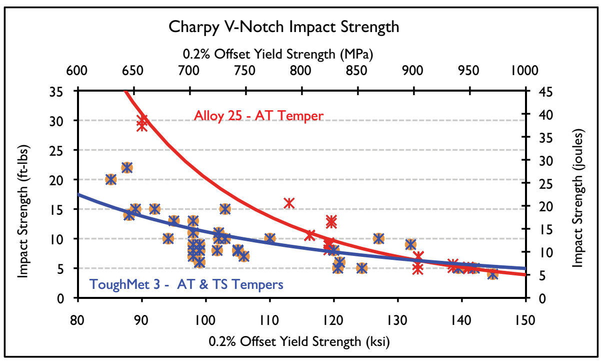
ToughMet® has been shown to be an ideal bearing material in situations where:

- the pin or mating part is steel
- the pin hardness > HRC 40
- the bearing pressure > 2,000 psi
- the load is not perpendicular to bushing axis
- the motion is reversing
- re-lubrication is difficult or impossible
- contamination or corrosion are likely

Material	Yield Stength	Young's Modulus	Elastic Resilience	Modulus of Resilience
	ksi	Mpsi	10^3 psi	10^3 psi
	MPa	GPa	MPa	MPa
Alloy 25 HT Copper Beryllium	195	19	10^3	1001
	1344	131	10^3	6899
ToughMet® 3 TS160U	150	20	7.5	563
	1034	138	7.5	3878
Spring Steel	140	30	4.7	327
	965	207	4.7	2252
Rubber	0.3	0.00015	2000	300
	2.1	0.0010	2000	2068
ToughMet® 3 CX105	105	20	5.3	276
	724	138	5.3	1900
C95510 Al Ni Bronze	70	17	4.1	144
	483	117	4.1	994
8620 Steel	91	30	3.0	138
	627	207	3.0	952
5052 Aluminum	26	10	2.6	34
	179	69	2.6	233
C93200 Pb Sn Bronze	18	15	1.2	11
	124	103	1.2	74

Resilience

The ability to withstand large amount of strain without yielding is termed elastic resilience. It is a combination of high strength and good flexibility (low stiffness). It can be calculated by dividing the yield strength by the elastic modulus. The term modulus of resilience describes the amount of strain energy a material can absorb without yielding. It represents the area under the elastic portion of the stress-strain curve, and can be approximated as one half of the square of the yield strength divided by the elastic modulus. ToughMet® and copper beryllium have the highest moduli of resilience among low friction bearing materials, as seen in the table at the right.

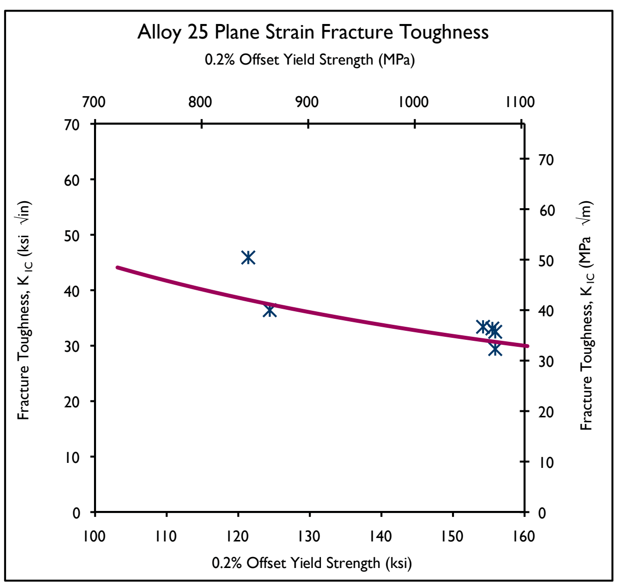


Impact Strength and Toughness

While resilience is a measure of the amount of strain or deformation that a material can absorb without yielding, toughness is a measure of the amount of energy a material can absorb without fracturing. It can be described as the amount of area underneath the stress-strain curves of a material.

One commonly used measure of toughness is impact strength, which measures the amount of energy required to fracture a specimen of a specific configuration. The chart below shows the room temperature Charpy V-Notch (CVN) impact strength of ToughMet® and copper beryllium Alloy 25.

The chart on the right shows another measure of the fracture toughness of Alloy 25, namely the K_{IC} value. This value provides a measure of how much energy is required to propagate an existing crack through the metal. Note that there is an inverse relationship between yield strength and toughness, as shown in both the CVN and K_{IC} data.

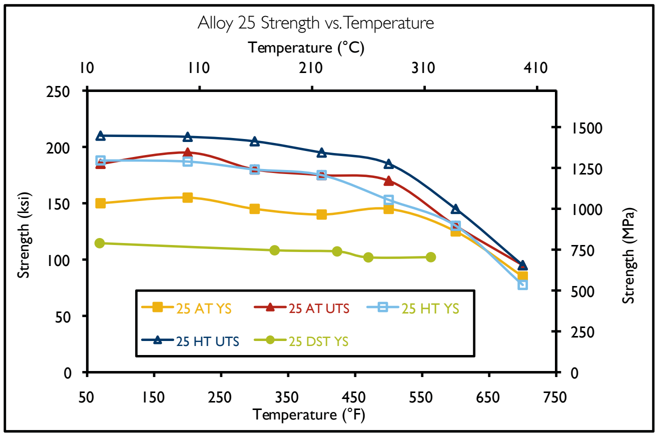


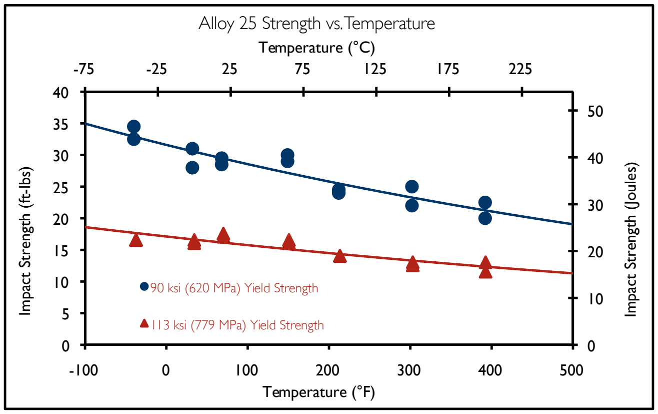
Elevated Temperature Properties

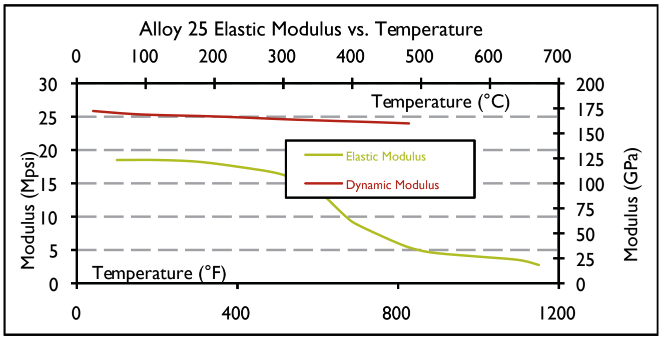
Elevated Temperature Strength

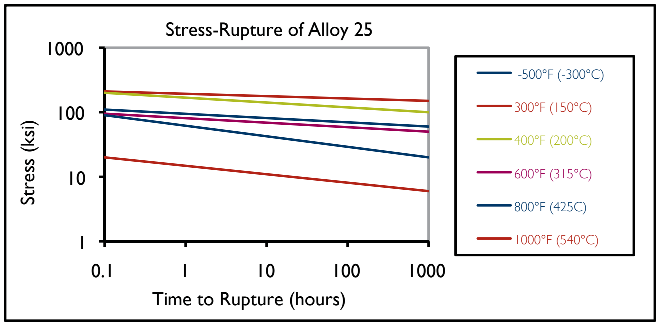
Copper beryllium Alloy 25 demonstrates good stability of tensile properties from cryogenic temperatures through 500°F (260°C) despite long exposure. When tested at elevated temperature at conventional strain rates, tensile properties retain essentially room temperature values through 500°F (260°C). The high conductivity copper beryllium alloys retain strength through about 800°F (425°C). The hardness of these alloys leads to their use in welding electrodes and mold components for plastic injection, as well as valve seats in racing engines.

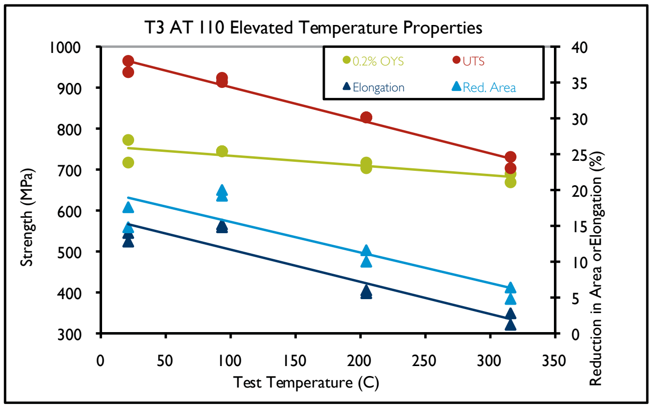
ToughMet® also is used in high temperature applications due to its excellent stress relaxation resistance and ability to maintain yield strength through 600°F (315°C). This allows the use of ToughMet® in high temperature applications such as valve guides in racing engines.

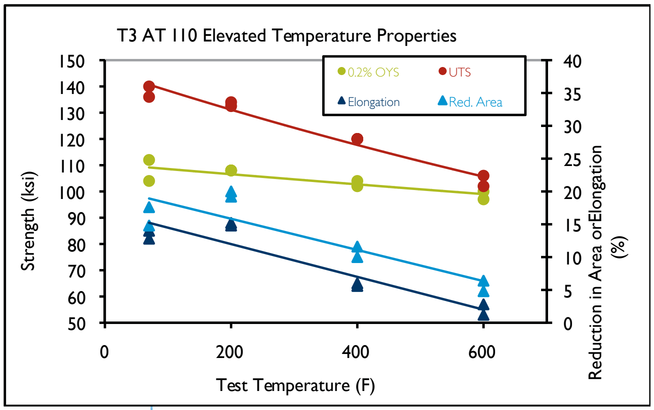








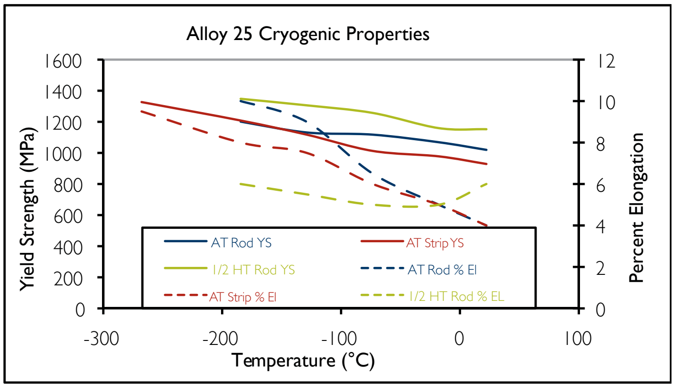


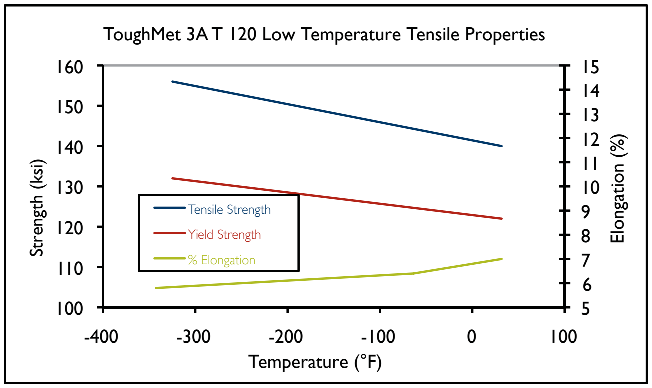


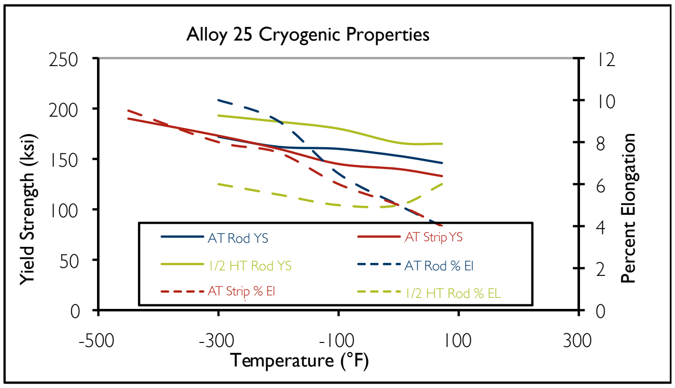
Cryogenic Properties

Cryogenic Behavior

Copper beryllium is used in liquid hydrogen and liquid oxygen due to its ability to maintain strength and toughness in cryogenic conditions. Copper alloys have no ductile to brittle transition temperature, as do many high strength steels. In fact, the strength of both copper beryllium and copper nickel tin tends to increase as the temperature drops. Furthermore, copper beryllium even tends to increase in ductility at lower temperatures.







Other Attributes

Reflectivity – Copper beryllium polishes readily to an optical mirror surface. Because of its color, this surface reflects light efficiently, especially in the infrared spectrum. Reflectivity, machinability and dimensional stability lead to its use in mirrors, particularly where centrifugal or other stresses are present.

Dimensional Stability – Besides increasing hardness and strength age hardening can relieve stress in copper beryllium. This results in high dimensional stability during machining or stamping. A conventional stress relief that does not alter strength, and various stabilizing thermal treatments are used.

Spark Resistance – One of the oldest and best known uses for copper beryllium is in hand tools for industrial processes where a spark is not permissible. A hot, copper rich particle dislodged on impact, cools rapidly and does not ignite. In addition to spark resistance, copper beryllium and ToughMet® have the hardness to provide lasting durability.

Special Surface Treatments – Surface modification of copper beryllium creates several unique possibilities. An oxide formed at high temperature greatly increases secondary electron emission. Various techniques have been used for local hardening. Laser and electron beam techniques have produced various surface states, ranging from localized solution annealing to glazing. Coatings have been applied for increased emissivity, hardening or appearance.

Appearance – The golden luster of high strength alloys and the coral tinted gold of the high conductivity alloys give copper beryllium an attractive appearance. ToughMet® 3 has a gold tinted silver appearance These alloys are polished and waxed or lacquered for application as decorative components.

Your Supplier

Materion Brush Performance Alloys' quality commitment exists throughout our vertically integrated corporation. Our commitment extends from the mining of beryllium ore to the manufacture of finished materials including pure beryllium, the oxide ceramic and numerous alloys on precise and efficient equipment.

This section summarizes a few facts about Materion Brush Performance Alloys, namely; history, corporate profile, mining and manufacturing, distribution, customer service and quality. Safe handling of beryllium-containing products is addressed in a special section. If you require additional information on any of the topics previously listed, please contact Brush Performance Alloys.

Company and Corporate History

Materion Brush Performance Alloys' historical roots extend back to 1931, when its predecessor company, The Brush Beryllium Company, was founded in Cleveland, Ohio, to commercially develop the beryllium technology of Brush Laboratories. Brush Laboratories was started in 1921 by Charles Brush, Jr. and Dr. C. Baldwin Sawyer, who pioneered work in the extraction of beryllium from ore and the production of beryllium metal, oxide and master alloys.

In the late 1940's, the Atomic Energy Commission (AEC) developed interest in beryllium powder metal technology and became the first significant user of metallic beryllium and beryllium oxide. During the 1950's, commercial applications for beryllium-containing materials grew, particularly copper beryllium. In 1953, The Brush Beryllium Company built a small commercial plant at Elmore, Ohio, to produce copper beryllium alloys. That facility is now the largest and most advanced facility for beryllium and beryllium-containing alloy production in the world.

In 1958, The Brush Beryllium Company purchased Penn Precision Products Company of Reading, Pennsylvania. This acquisition provided Brush Performance Alloys the capability to supply a full range of copper beryllium rolled strip products. The Reading facility now provides world class beryllium-containing strip, rod and wire alloys to meet the demand for these products.

During the 1960's, The Brush Beryllium Company acquired extensive mineral rights in the Topaz mountain area of Utah, and developed techniques for extracting beryllium from these bertrandite deposits. These ore reserves are sufficient in size to accommodate the global demand for beryllium and beryllium-containing alloys well into the future, and make Brush Performance Alloys the only fully integrated producer of beryllium, beryllium-containing alloys and beryllia ceramic.

In 1971, the Brush Beryllium Company purchased the S.K. Wellman division of Abex Corporation. The Brush Beryllium Company name was changed to Brush Wellman Inc. The S.K. Wellman division was later sold, but the name remained. Brush Wellman Inc. was listed on the New York Stock Exchange in 1972.

In 1980, Brush Wellman opened a new facility in Tucson, Arizona to produce beryllium-based ceramic products. This was augmented by a year later with the acquisition of a ceramics operation in Newburyport, Massachusetts, later renamed Zentrix technologies. The latter facility specializes in metallization of ceramics and ceramic packages for discrete RF and microwave devices and is now part of Materion Microelectronics and Services. The Tucson facility is now Materion Ceramics.

Brush Wellman's international organization was established in the 1980's with the formation of Brush Wellman GmbH (now Materion Brush GmbH) in Stuttgart, Germany. This was followed by Brush Wellman Ltd. (now Materion Brush Ltd.) in Reading, England; and Brush Wellman Japan Ltd. (now Materion Brush Japan Ltd.) in Tokyo, Japan.

In 1982, Brush Wellman further expanded its product portfolio by acquiring Technical Materials Inc. (now Materion Technical Materials) in Lincoln, Rhode Island. This facility specializes in specialty electroplated, clad, specialty contoured, and electron-beam welded strip.

In 1986, Brush Wellman acquired Williams Gold refining company in Buffalo, New York. This company was later renamed the Williams Advanced Materials Inc. This facility refined precious metals and produced thin foil and wire as well as sputtering targets for the Physical Vapor Deposition (PVD) industry. Williams and its subsidiaries now span four Materion Business Units (Microelectronics and Services, Large Area Coatings, Barr Precision Coatings and Thin Film Materials, and Advanced Chemicals).

In 1990, Brush Wellman acquired Electrofusion Corporation (now Materion Electrofusion) in Fremont, CA, which specializes in the fabrication and bonding of ultra-high vacuum (UHV) and other components made from beryllium metal and other specialty materials.

Brush Wellman Singapore (Pte) Ltd. (now Materion Brush Singapore Pte Ltd.) was formed in 1992 to provide local service and distribution in Southeast Asia.

In 1997, Brush Wellman opened a facility in Lorain, Ohio, to produce non-beryllium containing high performance copper alloys, including ToughMet® and MoldMAX® XL.

In 1998, Williams Advanced Materials expanded into the non-precious metal PVD market with the purchase of PureTech Inc (now part of Materion Microelectronics and Services) in Brewster, New York.

In May 2000 Brush Wellman Inc., Technical Materials Inc, Zentrix Technologies, and Williams Advanced Materials became wholly-owned subsidiaries of a newly created holding company, Brush Engineered Materials Inc. In addition, the foreign subsidiaries became wholly-owned subsidiaries of Brush Engineered Materials Inc.

Between the years 2000 and 2004 Brush Wellman established additional distribution, service and sales organizations to serve the growing Asian markets. These include what are now Materion Brush International Taiwan in Taipei, Taiwan; Materion Brush Singapore Shanghai in Shanghai, China; Materion Brush International Hong Kong in Hong Kong, China; Materion Brush (Japan) Ltd. Korea Representative Office in Incheon City, Korea; and Materion Brush (Singapore) Pte. Ltd. India Liason Office in Pune, India.

Williams Advanced Materials also greatly expanded in this era. In 2005, OMC Scientific Holdings (now part of Materion Microelectronics and Services) in Limerick, Ireland and Thin Film Technologies (now part of Materion Barr Precision Optics and Thin Film Coatings) in Buellton, California, were acquired. Thin Film Coatings employs a variety of thin film coatings deposition techniques and state-of-the-art photolithography. OMC Scientific Holdings primarily provides precision cleaning and reconditioning services for physical vapor deposition customers. In 2007, these capabilities were supplemented with the opening of a similar facility in the Czech Republic.

In 2006, Williams acquired CERAC, Inc. (now Materion Advanced Chemicals) in Milwaukee, Wisconsin. This facility has manufactured specialty inorganic materials, physical vapor deposition (PVD) materials since 1964, and is the leading manufacturer of PVD materials for optical applications in North America

In 2008, Williams acquired Techni-Met (now Materion Large Area Coatings) in Windsor, CT. This facility specializes in the PVD of inorganic materials (such as precious, refractory, non-magnetic metals, alloys and ceramics) onto flexible polymeric films.
In 2009, Williams acquired Barr Associates Inc. (now part of Materion Barr Precision Optics and Thin Film Coatings) in Westford, Massachusetts. Barr Associates is a manufacturer of precision thin film coatings and optical filters. This was followed shortly by the acquisition of Academy Corporation in Albuquerque, New Mexico (now part of Materion Microelectronics and Services as well as Materion Advanced Chemicals). This facility refines precious and non-precious metals.

Is 2011, EIS Optics was acquired. The company is a Shanghai-based producer of optical thin film filters and optical sub-assemblies, while also providing glass processing and lithography.

On March 8, 2011, Brush Engineered Materials Inc. became Materion Corporation. Brush Wellman Inc. became Brush Performance Alloys, and the other business units were renamed as detailed above. The unification of all of the Company's businesses under the Materion name is intended to create efficiencies and facilitate synergies. The new name, along with a new business unit alignment under the Materion brand, is expected to provide customers with better access and recognition to a broader scope of products, technology and value-added services.

Materion Corporate Profile

Materion Corporation (NYSE-MTRN), headquartered in Mayfield Heights, Ohio, supplies highly engineered advanced enabling materials to leading and dynamic technology companies across the globe. Our product offerings include precious and non-precious specialty metals, precision optical filters, inorganic chemicals and powders, specialty coatings and engineered clad and plated metal systems. It includes the following business groups:

Your Supplier

Materion Brush Performance Alloys

Alloy products are produced at the Elmore, Ohio; Lorain, Ohio and Reading, Pennsylvania, manufacturing sites. Research and Development laboratories are situated in Elmore, Ohio and at several other global locations. Products include:

Beryllium-containing Alloys including copper beryllium, nickel beryllium and aluminum beryllium master alloys are metallurgically tailored to meet specific customer performance requirements. Beryllium alloys are used in computers, telecommunications, automotive electronics, aerospace, oil exploration, undersea and marine environments, and plastic mold tooling marketed under the brand name MoldMax®

Other High Performance and Precious Alloys produced by Materion Brush Performance Alloys include the ToughMet® copper-nickel-tin spinodal alloys produced at the Materion Brush Performance Alloys Lorain, Ohio facility. High strength, lubricity, durability, corrosion resistance and thermal conductivity make these copper alloys a premier choice for plastic molding cavities and cores, heavy duty bushings and other severe service applications.

Materion Brush Beryllium and Composites

Metallic beryllium is a lightweight metal possessing unique mechanical and thermal properties. Its specific stiffness is much greater than other engineered structural materials such as aluminum , titanium and steel. Beryllium products, including AlBeMet® and E-materials, are primarily, but not exclusively, used in the defense and aerospace markets. Metallic beryllium is produced in Elmore, Ohio by Materion Brush Beryllium and Composites. Fabricated components are made at Materion Electrofusion in Fremont, California.

Materion Electrofusion

Materion Electrofusion focuses on beryllium X-ray window and ultra high vacuum (UHV) products that have been an integral part of the business since the 1970s. The unit also offers electron beam (EB) welding, vacuum furnace brazing and waterjet cutting services, as well as engineering support to help customers take advantage of these processes. In addition, Materion Electrofusion offers Truextent® brand acoustic beryllium products, such as speaker domes and microphone transducers.

Materion Ceramics

Beryllia Ceramic (BeO), is a high strength electrical insulator with thermal conductivity greater than many metals. BeO is used in high power electronic circuitry, laser equipment and microelectronics packaging. BeO is produced by Materion Ceramics at facilities in Tucson, Arizona, and Newburyport, Massachusetts.

Materion Technical Materials

Materion Technical Materials Inc. located in Lincoln, Rhode Island, produces inlay/overlay clad, electroplated and other specialty hybrid strip products in a wide range of alloys.

Materion Advanced Chemicals

Materion Advanced Chemicals provides high performance materials solutions for large area coatings, alternative energy and thin film, and specialty inorganic chemicals for semiconductors, LED lighting and energy storage applications.

Materion Barr Precision Optics and Thin Film Coatings

Materion Barr Precision Optics and Thin Film Coatings is one of the world's largest manufacturers of precision thin film coatings and optical filters. Capabilities include high-precision optical filter technology that allows the management of visible and non-visible wavelengths of light.

Materion Large Area Coatings

Materion Large Area Coatings is a high value-added manufacturer of precision-coated materials specializing in the physical vacuum deposition (PVD) of inorganic materials (such as precious, refractory, non-magnetic metals, alloys and ceramics) onto flexible polymeric films.

Materion Microelectronics and Services

Materion Microelectronics and Services is the leading supplier of thin film deposition materials, electronic packaging products, and high purity and specialty materials. The business also provides precision parts cleaning, precious metals refining and recycling, and other value-added services.

Materion Natural Resources

Materion Natural Resources is the world's primary source of commercially viable beryllium ore. It provides a timely and dependable supply of efficiently produced, high quality feed stock to support Materion's beryllium-based businesses.

For more information on Materion Corporation, and its products and services, please visit us online at www.materion.com.

Brush Performance Alloys Mining and Manufacturing

Delta

Materion Brush Performance Alloys begins production of beryllium containing alloys at its Topaz-Spor mining operation in Utah. Here the company operates the only bertrandite producing mine in the free world. Bertrandite ore is mined from open pits, and provides a constant source of ore for Brush Performance Alloys' extraction facility in nearby Delta, Utah. At Delta, the bertrandite ore is processed into a fine powder of beryllium hydroxide.

This hydroxide is transported to the Elmore, Ohio, manufacturing plant where alloy production begins.

Elmore

The Elmore, Ohio, plant is the primary thermo-mechanical processing facility for the Alloy Division.
Metallurgical and metalworking processes include:

- Reduction of beryllium hydroxide
- Melting and casting
- Hot and cold rolling
- Hot extrusion
- Cold drawing
- Annealing and precipitation heat treating
- Cleaning
- Flattening
- Straightening
- Sawing
- Strip plating
- Machining

The products of Elmore manufacturing are: strip, wire, rod, bar, tube, extruded shapes, custom products, plate, casting ingot and master alloy. These products are delivered worldwide to service centers for delivery to customers or to the Reading, PA finishing plant for further processing.

Reading

The Alloy Division's Reading, PA, facility produces finished gauge strip and wire products. A variety of metalworking processes are used:

- Rolling
- Drawing
- Pickling
- Annealing
- Precipitation hardening
- Degreasing
- Slitting and welding
- Straightening
- Pointing and chamfering
- Cutting to length
- Traverse winding of strip/spooling of wire

Some of the most advanced manufacturing techniques produce a consistent high quality family of products.

Strip is routinely rolled to thicknesses down to 0.002 inches (0.51 mm), rod is drawn to diameters as small as 0.030 inches (0.76 mm), and wire is drawn to diameters as small as 0.050 inches (1.27 mm).

The Reading, PA , plant is in close partnership with the Elmore, Ohio, plant. The latter supplies the input stock that the Reading plant turns into finished products. The Alloy Division maintains the highest standards of quality. This dedication to quality is the secret to the success of the Alloy Division and its key to the future.

Lorain

The Lorain, Ohio, plant processes alloys which do not contain beryllium. Its manufacturing processes include:

- Melting and casting (including cast shapes)
- Annealing and heat treating
- Cleaning
- Sawing
- Machining

Product Distribution

Materion Brush Performance Alloys maintains a worldwide network of service centers, independent distributors and authorized agents. People in this network can answer your inquiry, process your order and assist with your special requirements. They are responsive to your requests for technical information and have available the complete resources of the Brush Performance Alloys organization.

Materion Brush Performance Alloys Service Centers

There are two North American and four International Brush Performance Alloys' service centers. Addresses, telephone and facsimile numbers are listed on the back cover of this book and on www.materion.com. These service centers:

- Provide local technical and distribution service to customers on all aspects of the use of Brush Performance Alloys alloys, including application engineering, design assistance, safe usage of all the products and alloy selection.
- Maintain stock of copper beryllium and non-beryllium containing copper alloy products in a wide range of alloys, tempers and sizes.
- Provide rapid delivery of products to customer requirements throughout the United States, Canada and all international locations.
- Provide precision slitting, sawing, leveling, traverse winding and other custom services to meet your exacting requirements.
- Work closely with customers to satisfy individual needs for import administration, packaging, labeling and special material properties.

Materion Brush Performance Alloys Representative Offices

There are several global representative offices. The services they provide include:

- Provide local technical and distribution service to customers on all aspects of the use of Brush Performance Alloys alloys, including application engineering, design assistance and alloy selection.
- Ensure that customer requirements are met by the appropriate Brush Performance Alloys company or Brush Performance Alloys Independent Distributor.

Independent Distributors

Brush is represented by independent distributors in more than 70 locations in the United States, Canada and in most other countries. The Independent Distributors make available many of the same product distribution and technical marketing services of the Materion Brush Performance Alloys Service Centers and provide customers with a local contact for rapid response, including:

- Maintain local stocking programs of alloy products for prompt delivery to their customers.
- Have staff that have been trained by Materion Brush Performance Alloys on the latest developments in Materion Brush Performance Alloys alloys, and can provide local language service for local customers.
- Provide access to all Materion Brush Performance Alloys resources.

For the most current listings of Brush Performance Alloys' Representative Offices and Distributors, please visit us online at http://materion.com/brushalloys/contactus.

Customer Service

Materion Brush Performance Alloys' broad coverage of customer service is offered through:

- Alloy Sales Engineers
- Regional Alloy Service Centers, with customer service personnel
- Sales and Marketing located in Mayfield Heights, Ohio

Brush Performance Alloys customer service personnel can draw upon a wide range of Brush Performance Alloys resources. These include:

- Alloy Technical Service
- Current technical literature on each product
- A technical library with electronic database systems
- Environmental Engineering Staff
- Manufacturing and Facilities Engineering Personnel
- Custom Fabrication Engineering

In addition, we welcome your comments about our products, ones you are currently using and those you would like to see developed in the future. Also, since copper-based alloys are recyclable products, we welcome your inquiries about copper-based solid or liquid residuals.

Materion Brush Performance Alloys' strength lies in our team of exceptional technical, manufacturing and customer support members. We have assembled an impressively credentialed staff of experts in materials science, component design and manufacturing methodologies. From assistance with product design and development to innovative manufacturing practices as well as courteous and accommodating customer service, our team members work with customers to provide material solutions that best meet their individual needs.

Our technical service staff is prepared to assist you with material selection, design assistance and review including finite element analysis (FEA), fabrication and processing assistance, reprocessor recommendations, failure analysis, material evaluation, material sample supply and safe handling information. We also are continually producing technical literature, and are more than willing to provide in-house technical seminars at our customers' locations.

Our technical service center is prepared to extend its considerable technical expertise to your staff. Whether you need design assistance, failure analysis or educational programming, our technical staff of metallurgists, mechanical engineers and application engineers are your resource and partner.

Customer Technical Service Mission Statement:
We will respond to our customer's technical needs in a fast, professional and courteous manner. We will promote our technical services and expertise, ensuring that customers will appreciate and make use of the added value of Materion Brush Performance Alloys' products. We will strive to meet and exceed our customers' expectations in terms of providing world-class service. Each customer should feel important, and come away from any dealing with us with the impression that they have received a professional and thorough response.

Quality

Materion Brush Performance Alloys is committed to our customers' success. Therefore, we strive to provide the highest quality products and services in the market. We serve some of the most demanding markets in the world when it comes to quality of systems, products, distribution services , and have been recognized for our quality, excellence and leadership in these highly demanding markets. We support our products with superior service capabilities as well as an outstanding world-wide service center distribution network.

We base our quality initiatives on the Lean Six Sigma and Supply Chain Management philosophies of eliminating wasteful activities, reducing variation, and improving system performance. Lean Production drives a relentless elimination of "waste" - producing what is needed, when it is needed, in exactly the right quantities, with a minimum amount of resources. Six Sigma is a process-focused data-driven problem solving discipline that drives variation reduction and the elimination of process defects. Supply Chain Management optimizes the material flow to facilitate production from the supply base through internal operations to our customers. To maintain high standards of quality, we provide ongoing training in the quality tools to all employees.

Materion Brush Performance Alloys Approach to Quality

- World class safety practices to provide an injury and illness free workplace.
- Lean manufacturing to reduce cycle times, increase capacity and provide industry leading service to our customers.
- Supply chain management to provide exactly what is needed, when it's needed, to where it's needed in exactly the right quantity for the right cost; reduce inventory and streamline material and information flows.
- Six Sigma to provide industry leading product consistency and quality and to reduce cost.
- Total productive maintenance to provide industry leading equipment reliability.

Quality Certifications

All Brush Performance Alloys facility quality certifications are accessible on our website at www.materion.com/BrushAlloys.

The Elmore, Reading, Lorain and Warren facilities are certified to **ISO 9001:2000** and **AS9100-B**. The Elmhurst facility is certified to **ISO 9001-2000**. The Elmore and Lorain facilities are also NADCAP accredited for heat treatment. The Quality Management System (QMS) monitors internal and external product performance along with the implementation of the quality system. Overall performance tracking and monthly reviews utilize measurements developed by the management teams at each plant.

ISO/IEC 17025:2005

The Reading Plant Production Mechanical Testing and the Elmore Plant Chemical Analysis and Metallurgical Laboratories have received accreditation to **ISO/IEC 17025:2005** by the American Association of Laboratory Accreditation (A2LA). The requirements of this standard include and go beyond the relevant requirements of **ISO 9001:2000**. Some of the requirements are as follows:

- Laboratory Quality Manual.
- Determination of the Best Test Method.
- Measurement systems for gauge repeatability and reproducibility studies.
- Calibration control.
- Training procedures that insure operator competency.
- Purchase and maintenance records on the major item of equipment.

To provide evidence of our quality, we:

- Provide **material certifications** that report test results demonstrating compliance to customer specifications.
- Provide details of statistical process capability and product quality on request.
- Encourage visits to our operating facilities for the purpose of auditing our quality systems that meet the requirements of **ISO 9001:2000, AS9100, and ISO/IEC 17025:2005.**

We are dedicated to excellence in customer satisfaction by providing superior products and services.

Health & Safety, Environment and Recycling

Safe Handling of Copper Beryllium

Handling copper 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 Material Safety Data Sheet (MSDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, visit us online at www.materion.com, or contact Materion Brush Performance Alloys in Mayfield Heights, Ohio, at 800.321.2076.

Environmental 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. It is important to note that copper alloys with up to 4% lead added for machinability are exempt from these restrictions.

Copper beryllium alloys 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. Furthermore, copper beryllium alloys are not banned, restricted or otherwise limited by the Joint Industry Guide for Material Composition Declaration Guide in Electronic Products (JIG).

Recycling of Copper Beryllium

Copper beryllium scrap that is not contaminated with other metals such as iron, aluminum, cadmium, lead etc. is readily recyclable by the primary producers and other recyclers. Furthermore, copper beryllium alloys are all fully compliant with the RoHS directive. It is economically and environmentally advisable for the manufacturer or a recycler to segregate copper beryllium scrap from other metals for recycle.

Brush Performance Alloys purchases clean copper beryllium scrap for reprocessing into new copper beryllium alloys. All copper beryllium alloys except M25 (C17300) are recyclable. For a list of companies that collect and recycle copper beryllium scrap, electrical and electronic scrap, contact Brush Performance Alloys at 800.289.2328, in the US and Canada, or contact your local sales representative.

Disposal of Copper Beryllium

Copper 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 2002 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. In addition, one very significant property of copper beryllium is its corrosion resistance which is demonstrated by the fact that copper beryllium housings are specifically used to protect the electronics in trans-oceanic communications cables from the corrosive effects of seawater. Due to the fact that beryllium is not a hazardous waste constituent and copper beryllium is not a listed hazardous waste under federal rules and regulations, wastes cannot be classified as hazardous due to the presence of copper beryllium alloys.

If you have any questions regarding the above information, please contact your sales representative or call the Product Safety Hotline at 800.862.4118. Get product specific material safety data information at www.materion.com/BrushAlloys.

Recycling of Other Alloys

You can call Brush Performance Alloys at 800.289.2328. to get help in recycling your scrap, or you may contact your local sales representative. Brush Performance Alloys will provide detailed packaging and shipping instructions. The scrap should be kept clean and free of oils and other potential contaminants that may reduce the value of the scrap. Scrap should be segregated by alloy. Brush Performance Alloys also may direct you to local scrap dealers for recycling of small quantities of scrap.

Environmental, Health, & Safety

VALUES

The protection of people and the environment are our highest priorities. Work is to be performed safely in a manner that encourages the health and well-being of people and the environment.

POLICY

It is the policy of Materion Corporation to design, manufacture and distribute products and to manage, recycle, and dispose of materials in a safe, environmentally responsible manner.

PRINCIPLES

In support of our Environmental, Health and Safety Policy, the following principles have been developed to provide additional direction on specific issues and accountabilities.

- **We believe that incidents, injuries, and illnesses, are preventable.** We utilize a thorough and disciplined Health and Safety Management System for maximizing worker protection.
- **Line management is responsible** for integrating these environmental, health and safety principles into daily work activities and for diligently responding to employee concerns.
- **We share accountability, but are individually responsible.** To be successful, we promote the acceptance of individual responsibility for environmental, health and safety issues. Each employee is responsible for maintaining an awareness of safe work practices and preventing conditions that may result in an unsafe situation or harm the environment. No operation or task will be performed in a knowingly unsafe manner. It is the responsibility of each employee to promptly notify management of any adverse situation.
- **We are committed to utilizing our resources and technical capabilities** to educate, train, and protect the health and safety of our employees and visitors, our customers and vendors, the general public and the environment.
- **We utilize measurements and accountabilities** for managing our environmental, health, and safety programs and support them by assessing performance within our management system framework.
- **We promote the safe and environmentally responsible use and handling of our products** and materials. We work to meet or exceed all regulatory requirements through proactive education, distribution of literature, and issuance of hazard communications to our customers, vendors, distributors, and contractors.

Richard J. Hipple

Richard J. Hipple
Chairman and Chief Executive Officer
Materion Corporation