MATERION BRUSH BERYLLIUM & COMPOSITES

Elmore Ohio 43416 • Phone 419/862-2745 • TWX 810/490-2300

Beryllium as a Heat Sink

Beryllium is an extremely efficient heat sink material because it can absorb more heat energy for an equivalent increase in temperature than the same weight or the same volume of any other metal. Beryllium's high thermal diffusivity indicates the ability to transfer heat rapidly and uniformly. This superiority of beryllium to absorb and conduct heat exists up to a melting temperature of 2345° F.

Significant heat sink properties of beryllium are compared with other materials in Table 1.

In addition to superior heat transfer capabilities, beryllium has a low coefficient of thermal expansion nearly equal to that of steel. This compatibility is useful in avoiding thermal stress when joining the two metals.

Beryllium can absorb about four times more heat than an equal weight of steel for the same temperature rise. Expressed differently, the increase in temperature in a beryllium heat sink per unit of heat absorbed, is only one-third that of a steel heat sink the same weight. Table 2 presents the advantages of beryllium when compared to other materials based on heat absorption and weight. Table 3 shows beryllium will weigh about one-fourth as much as steel for the same temperature rise and heat energy absorbed.

Table 1 - PROPERTY COMPARISON

MATERIAL	SPECIFIC HEAT Btu/(lb•°F)	MELTING POINT °F	THERMAL CONDUCTIVIY* Btu/ (ft • hr -°F)	DENSITY lb/cu in	COEF. OF THERMAL EXPANSION* in/in/°F x 10^{-6}
BERYLLIUM	.63	2345	75	0.067	8.0
MAGNESUM	.25	1204	77	0.066	16.0
ALUMINUM	.22	1220	99	0.100	14.0
STEEL	.12	2740	21	0.283	7.5
TITANIUM	.14	3000	11	0.165	5.5
COPPER	.09	1981	220	0.322	10.0

*Averaged from 500 to 1000°F

MATERION BRUSH BERYLLIUM & COMPOSITES
14710 W Portage River South Rd
Elmore, OH 43416-9502
phone: 419.862.4533 or 419.862.4171 Intl: 419.862.4127
e: berylliumandcomposites@materion.com

MATERION CORPORATION
www.materion.com/beryllium

MATERION

Table 2 - TEMPERATURE RISE* DUE TO HEAT ABSORPTION

	HEAT ABSORBED–Btu/lb			
	100	200	300	400
BERYLLIUM	280°F	470°F	630°F	790°F
MAGNESUM	480°F	830°F	1160°F	MOLTEN
ALUMINUM	520°F	900°F	MOLTEN	MOLTEN
STEEL	860°F	1350°F	1880°F	MOLTEN
TITANIUM	860°F	1450°F	2080°F	2520°F
COPPER	1010°F	MOLTEN	MOLTEN	MOLTEN

*From 70°F

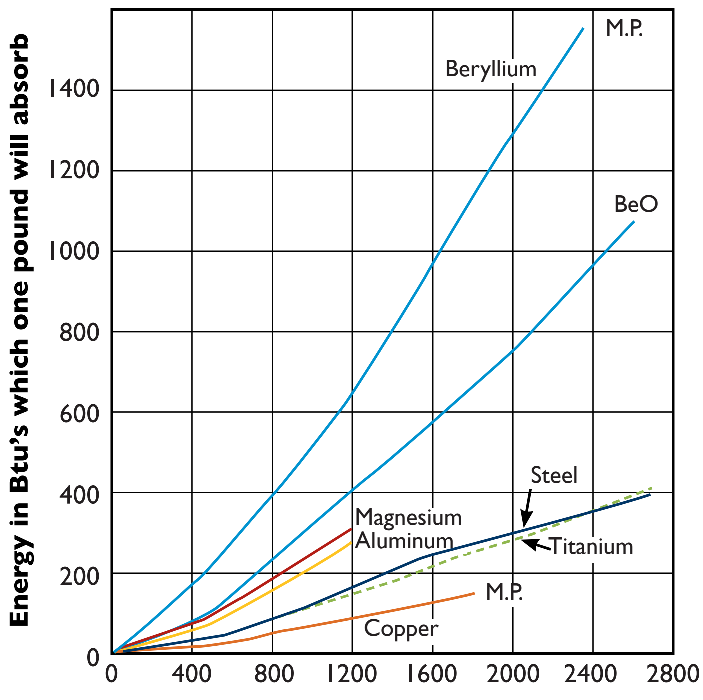
Table 3 - TYPICAL WEIGHT (in lbs.) FOR EQUAL HEAT ABSORPTION FOR HEAT SINK TEMPERATURE RISE OF 500 to 1000°F

BERYLLIUM	1
ALUMINUM	2.5
STEEL	4.4
COPPER	5.5

MATERION BRUSH BERYLLIUM & COMPOSITES
14710 W Portage River South Rd
Elmore, OH 43416-9502
phone: 419.862.4533 or 419.862.4171 Intl: 419.862.4127
e: berylliumandcomposites@materion.com

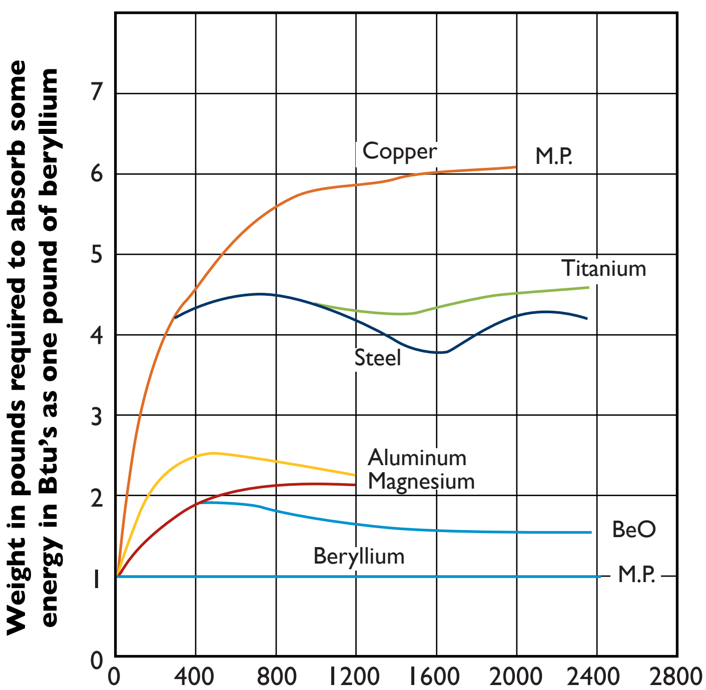
MATERION CORPORATION
www.materion.com/beryllium

FIG. 1



*From 70°F

FIG. 2



*From 70°F

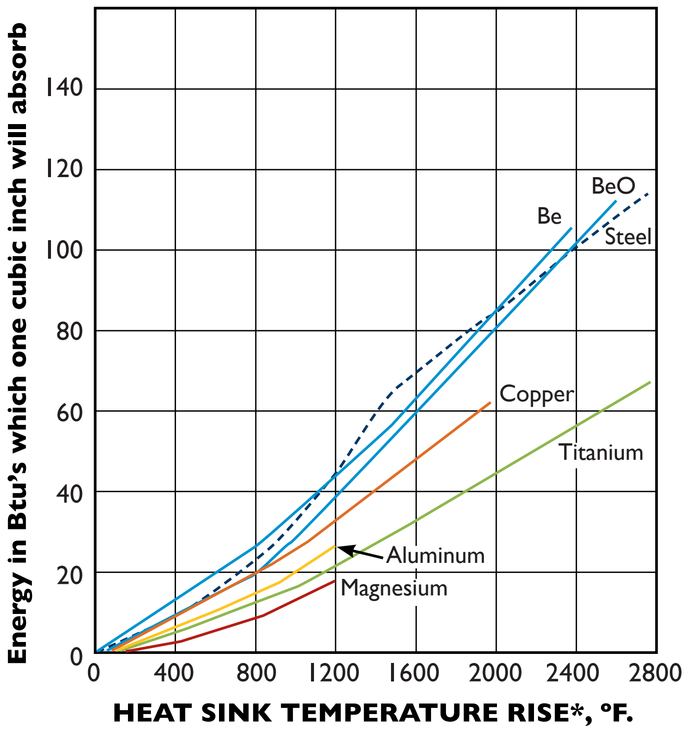
COOL HEAT SINK
Figure 1 shows that for equal heat sink weight and the same amount of BTU's to be absorbed, beryllium heat sinks will operate at much lower temperatures than heat sinks made from other materials. This factor is an important design consideration when it is necessary to minimize the temperature rise in parts adjacent to the heat sinks.

LIGHT WEIGHT HEAT SINK
The actual weight savings that can be realized by the use of beryllium in heat sinks is shown in Figure 2. Steel and titanium would weigh about four times as much as beryllium heat sinks in order to absorb the same energy. For the same energy to be absorbed, copper heat sinks would be about six times heavier, aluminum and magnesium would be about twice as heavy as beryllium.

MATERION BRUSH BERYLLIUM & COMPOSITES
14710 W Portage River South Rd
Elmore, OH 43416-9502
phone: 419.862.4533 or 419.862.4171 Intl: 419.862.4127
e: berylliumandcomposites@materion.com

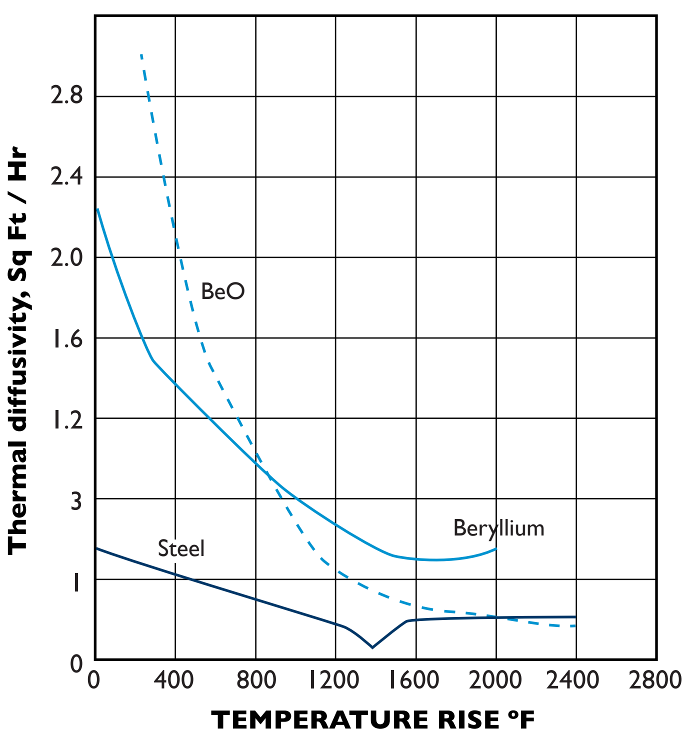
MATERION CORPORATION
www.materion.com/beryllium

FIG. 3



*From 70°F

FIG. 4



COMPACT HEAT SINK

Figure 3 compares the heat energy absorption capability of beryllium and the other materials on an equal volume basis. In this case beryllium and steel are superior to copper, titanium and magnesium. Although steel is close to beryllium on an equal volume basis, temperature equalization will occur much faster in the beryllium heat sink. This is shown in figure 4.

RAPID TEMPERATURE EQUALIZATION

A high temperature gradient in the heat sink can lead to hot spots, causing localized melting, warping and possible failure of the heat sink. The rate of temperature equalization which takes place in a body without internal heat generation depends only on the value of the materials' thermal diffusivity, which is expressed as follows:

$$\text{Thermal Diffusivity} = \frac{\text{Thermal Conductivity}}{\text{Density X Specific Heat}}$$

MATERION BRUSH BERYLLIUM & COMPOSITES
14710 W Portage River South Rd
Elmore, OH 43416-9502
phone: 419.862.4533 or 419.862.4171 Intl: 419.862.4127
e: berylliumandcomposites@materion.com

MATERION CORPORATION
www.materion.com/beryllium

FIG. 5

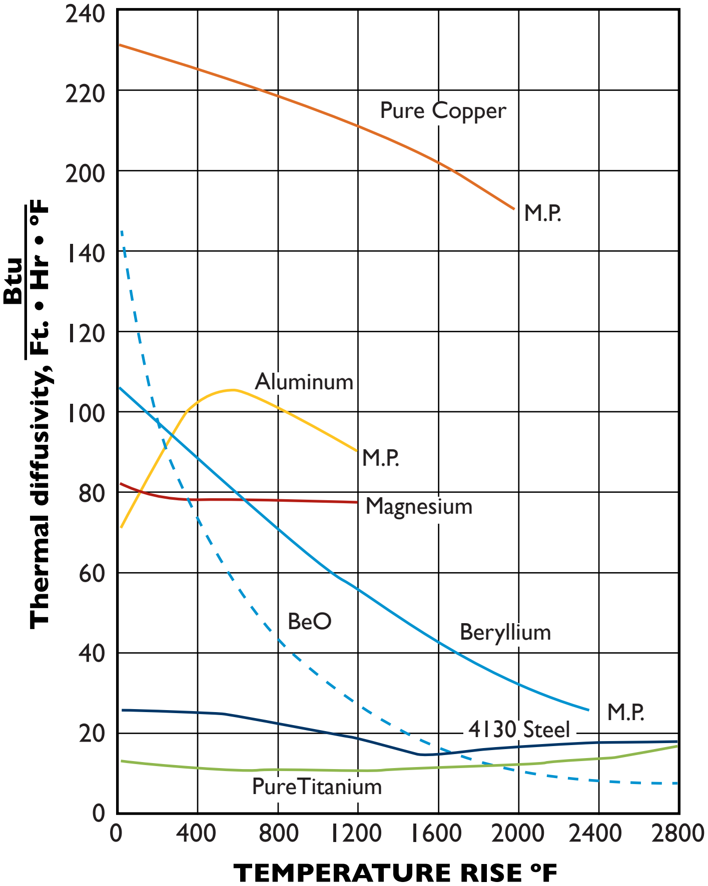
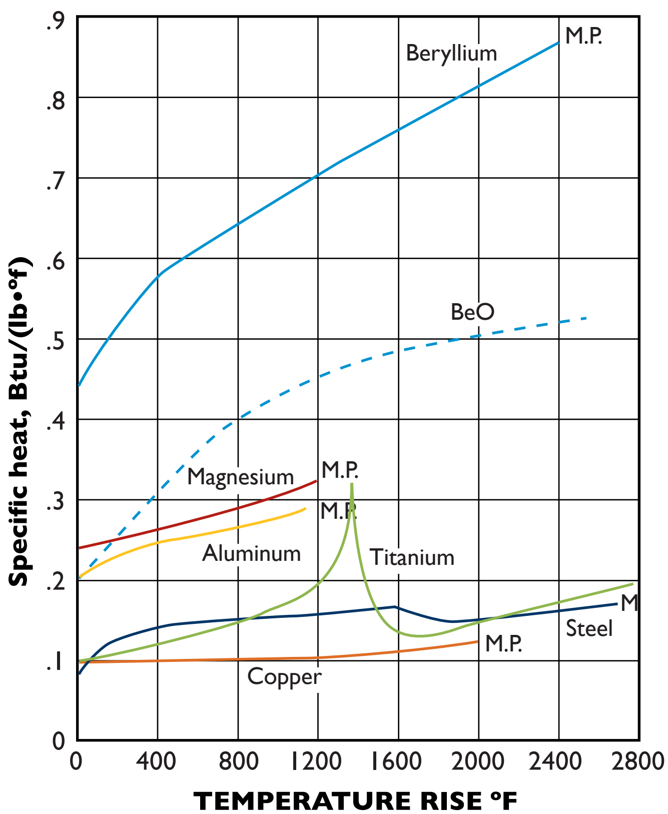


FIG. 6



THERMAL CONDUCTIVITY

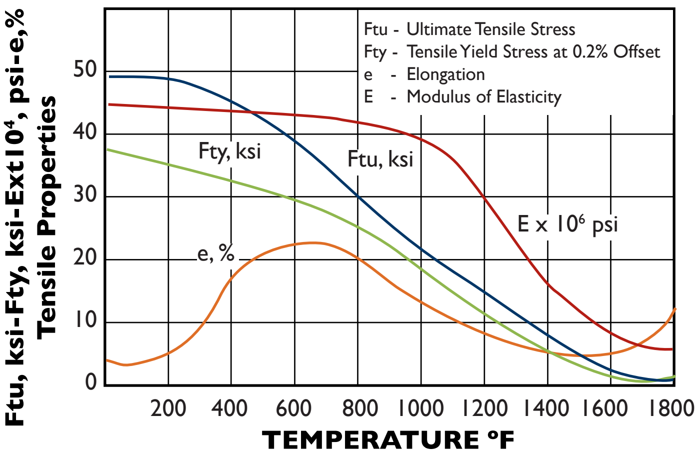
The graph to the right shows beryllium's excellent thermal conductivity. The high thermal conductivity will result in an even temperature throughout the heat sink.

SPECIFIC HEAT

The graph to the right shows beryllium's superior specific heat, when compared to other materials. This superiority exists up to the melting temperature of beryllium.

FIG. 7

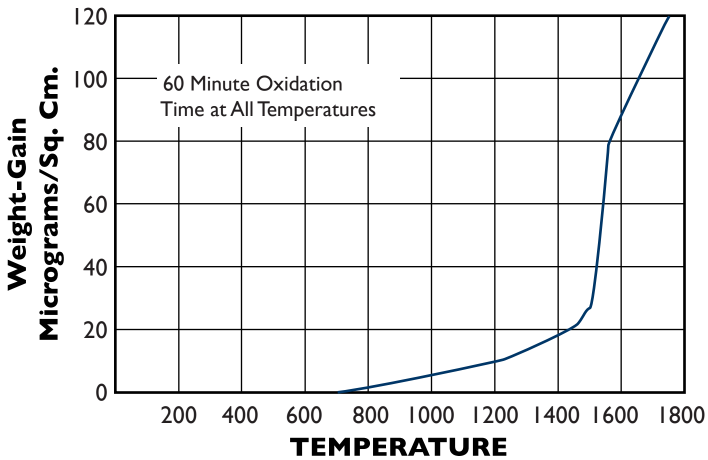
Strain Rate - .005/Min. To Yield Then .05/Min. To Fracture



TYPICAL MECHANICAL PROPERTIES IN TENSION OF S-200 HOT-PRESSED BERYLLIUM

The strength of beryllium at high temperatures contributes to its usefulness as a structural heat sink. Figure 7 shows the effect of temperature on the tensile properties of hot-pressed beryllium.

FIG. 8



OXIDATION RESISTANCE

When exposed to air, beryllium forms a protective oxide coating, similar to aluminum. The coating protects beryllium when subjected to re-entry conditions, which would cause other metals to burn. The oxide film also contributes to beryllium's resistance to damaging oxidation up to 1500°F.

MATERION BRUSH BERYLLIUM & COMPOSITES
14710 W Portage River South Rd
Elmore, OH 43416-9502
phone: 419.862.4533 or 419.862.4171 Intl: 419.862.4127
e: berylliumandcomposites@materion.com

MATERION CORPORATION
www.materion.com/beryllium

References:

THERMAL CONDUCTIVITY

Aluminum, Copper and Titanium — Touloukian, Y. S., February, 1966 Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides.
Beryllium — The Brush Beryllium Company, 1962 Beryllium in Aero / Space Structures.
Beryllium Oxide — The Brush Beryllium Company, 1967 Ceramic Products.
Magnesium — Goldsmith, Alexander et al, 1961 Handbook of Thermophysical Properties of Solid Materials, Vol. 1.
Steel — Hoyt, Samuel S., 1954 ASME Handbook.

SPECIFIC HEAT

Aluminum, Copper, Magnesium, Steel and Titanium — Goldsmith, Alexander et al, 1961 Handbook of Thermophysical Properties of Solid Materials, Vol. 1.
Beryllium — The Brush Beryllium Company, 1962 Beryllium in Aero / Space Structures.
Beryllium Oxide — The Brush Beryllium Company, 1967 Ceramic Products.

OXIDATION RESISTANCE

Beryllium — White, D.W., Jr., and Burke, J. E. 1955 The Metal Beryllium: p 180.

Beryllium as a Heat Sink

The heat sink properties of beryllium can be effective in improving the operation of components such as clutches, brakes, motors, electric circuit breakers and electronic "black boxes." Products requiring lighter weight, less volume, greater ability to contend with surges of heat, greater thermal transfer and dimensional compatibility and stability can benefit from beryllium.

Aircraft brakes are a notable application for beryllium. The C-5 "Galaxy" is using beryllium as a brake heat sink and will be about 1,600 pounds lighter because of beryllium. Additionally, the Brushsupplied aircraft brake grade (BG 170A) beryllium is performing all the structural requirements of a brake disk by taking the load generated by the torque from the wheel. The cost effectiveness of beryllium as a heat sink for aircraft brakes has been conclusively proven in this program.

Greater heat absorption, less temperature rise and lighter heat sinks all contribute to a longer life of the disk, tire and hydraulic components of an aircraft. Also, lighter aircraft brakes mean less inertia and lower bending moments in the landing gear structure and as a result, the gear and its mountings can be lighter.

The heat sink characteristics, light weight, stiffness and strength of beryllium contribute to the efficiency of SNAP-27, a thermo-electric power unit designed for man moon explorations. Since emissivity is dependent upon area and more area per pound can be obtained from beryllium, this metal is an ideal space radiator. The beryllium furnished by Brush is used throughout the structure and in radiator fins to dissipate the heat developed when electricity is generated.

The thermal properties and low weight of beryllium have also been employed in thrust vector control rocket nozzles.

Beryllium is frequently employed as a re-entry heat shield for space vehicles. Brush has supplied beryllium shields for a number of research vehicles, including the Project Fire manned re-entry vehicle study program conducted in 1964. This beryllium shield was exposed to 20,000°F for 42 seconds by firing a rocket to increase the rate of descent and produce the most severe re-entry conditions. The project supplied data which will contribute to the Apollo Project as well as the design of vehicles for Mars and Venus flights.

In addition to successful performances of beryllium heat shields during suborbital flights of Mercury capsules, beryllium produced by Brush, was made into shingles to protect the re-entry control section and rendezvous and recovery section of the Gemini capsules.

Each of these programs demonstrate Brush's broad and successful background in heat sink applications.

Brush Wellman Inc. has material engineers, structural designers and fabrication engineers to assist customers in the design of any application involving beryllium. For further information on Brush's technical services or products write Brush Wellman Inc. 17876 St. Clair Avenue, Cleveland, Ohio 44110.

MATERION BRUSH BERYLLIUM & COMPOSITES
17876 St. Clair Avenue • Cleveland, OH 44110
Telephone: (216) 486-4200
800-321-2076

Manufacturing Centers:
Elmore, OH and Reading, PA

Note:
Handling Aluminum-Beryllium Alloys 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 Aluminum Beryllium Alloys, contact Brush Wellman Inc.