

Light Alloy Super Cones: The Keronite Story

By Steve Mowry

Keronite (www.keronite.com) is a coating process for light metal alloys that resembles anodizing in that it uses an electric power supply and an electrolyte bath. However, it is significantly different from anodizing in that it produces much harder and thicker coating layers while using environmentally less harmful alkali electrolytes and a specially modulated AC voltage. Keronite coating involves producing a plasma discharge around a component immersed in an electrolyte that provides surface oxidation as well as the potential for elemental co-deposition. Keronite has been successfully applied to aluminum, magnesium, and AlBeMet (aluminum-beryllium metal alloys).

THE PROCESS

The coating consists of three layers (Fig. 1).

- I. External layer—30-40% of total thickness. Micro-hardness of 500-1000 HV, porosity > 15%. Excellent base for bonding.
- II. Functional hard layer—up to 200 μ m thick. Micro-hardness of 900-2000 HV, porosity 2-15%.
- III. Thin transitional layer—up to 5 μ m thickness between the base metal and the ceramic upper layers. This provides an atomic level bond between the Keronite coating and the substrate.

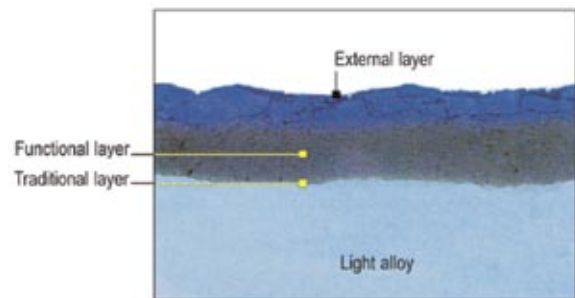


FIGURE 1: A section illustration of Keronite-coated light alloy.

The Keronite process involves fewer stages than hard/deep anodizing, making the whole process shorter than conventional methods and therefore more cost effective. Operating at room temperature (10-50°C) makes the Keronite process easier to use and decreases the time and cost of cooling. Additionally, the need for only half the volume of rinse water adds to cost savings and environmental friendliness.

The total cost of the process is then comparable with hard anodizing. Although energy consumption is higher for the Keronite process, the cost of Keronite electrolytes is lower than for conventional anodizing; these electrolytes do not contain environmentally hazardous components. They can be disposed of via a main drainage system without further treatment.

Keronite technology is based on the principles of plasma electrolytic oxidation (PEO) whereby a modulated electrical current is passed through a bath of proprietary electrolyte solution, converting the surface of light alloys into a dense, hard ceramic (Fig. 2). Parts are suspended from a bus bar and submerged in the electrolyte inside a stainless steel electrode cage. During the process, a controlled plasma discharge is formed on the surface of the light alloy substrate, fusing the oxides of the alloy into a harder

physical phase.

During the process, a modulated electrical current is passed through a bath of proprietary Keronite electrolyte solution. Parts are suspended from a bus bar and submerged in the chromium-free, low concentrate alkaline electrolyte inside a stainless steel electrode cage. Different electrolytes are required for aluminum and magnesium or new electrolytes can be designed to meet specific surface requirements but all are free from heavy metals and contain no ammonia or any acids.

As the pulsed AC current is passed through the bath, a controlled plasma discharge is formed and sparks are generated on the substrate surface. This plasma discharge converts the surface of the substrate into a complex ceramic by:

- Oxidation of the surface
- Elementary co-deposition
- Fusion of the ceramic layer

Because of the nature of the process, the Keronite layer is self-regulating and a uniform thickness is automatically achieved, even along the edges and inner surfaces of complex shapes. As an immersion process, Keronite has much greater throwing power than plasma sprayed ceramic surfaces or other line-of-sight processes.

Processing time depends on the thickness of the Keronite layer required and the size of the parts being treated. The protective ceramic layer will typically grow partly above and partly below the surface at around 1 micron per minute in the case of aluminum and up to 4 microns per minute on magnesium surfaces.

As a ceramic, Keronite is resistant

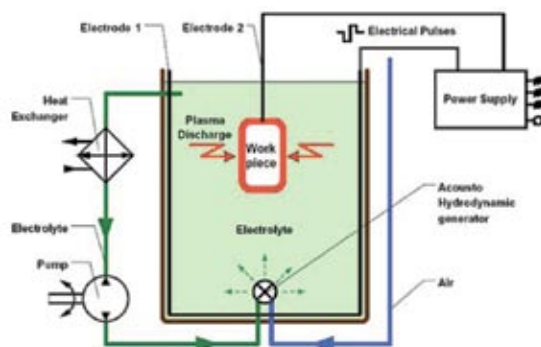


FIGURE 2: An illustration of the Keronite process.

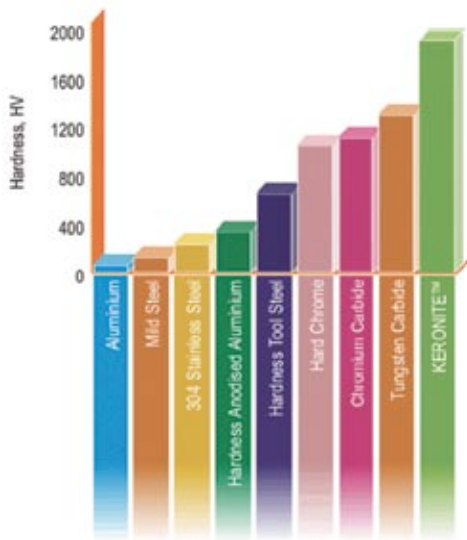


FIGURE 3: Material hardness.

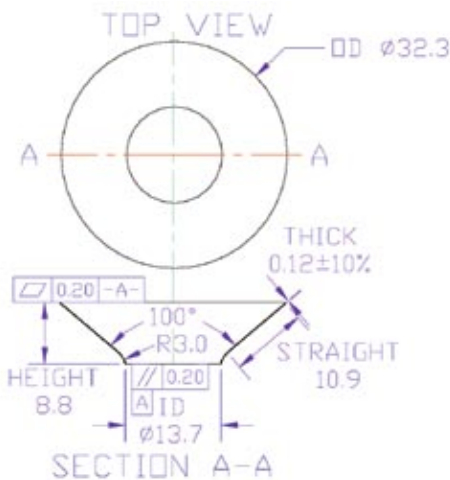


FIGURE 4: The cone geometry used for simulations.

to most chemicals and therefore performs extremely well in most corrosive environments in protecting the surface of magnesium, aluminum, or AlBeMet against atmospheric or galvanic corrosion. One of the key factors limiting the wider use of alloy cones is that of their poor resistance to corrosion. Keronite provides protection far superior to that of conventional conversion coatings or anodizing techniques.

Independent tests have revealed that magnesium alloy, coated with 35µm of Keronite, will survive one month of immersion in a saline solution, or 1000 hours in a salt spray environment without significant visual evidence of corrosion attack. Keronite has the stiffness and hardness of ceramic with excellent corrosion resistance. This ceramic is similar to Spinel and Ruby—very hard—with the related magnesium and aluminum oxide compounds. Cones coated with Keronite are well suited to automotive, professional, and even marine applications. Just how hard is Keronite? **Figure 3** illustrates hardness

relative to other common materials.

SIMULATION

Alloy and Keronite material properties are shown in **Table 1**. Note that AlBeMet 140 is 40% beryllium—60% aluminum and AlBeMet 162 is 62% beryllium—38% aluminum.

Are you thinking what I am? Can I get the low-density/medium-speed of sound magnesium to perform like AlBeMet 140 if I apply Keronite? I will simulate that using S.M. Audio's proprietary 1d composite finite element natural frequency analysis with lumped boundary conditions. The voice coil, spider, surround, et al. are replaced with two springs and two masses. The magnesium cone after the Keronite process was assumed to form the following sandwich structure: 0.03mm Keronite/0.06 magnesium/0.03 Keronite versus 0.12mm thick AlBeMet 140. All simulations use the geometry illustrated in **Fig. 4**.

Here is a summary of a Keronite/Mg/Keronite cone-assembly simulation results.

TABLE 1 Material properties of Keronite and alloy materials

MATERIAL	Al	Mg	AlBeMet 140	AlBeMet 162	Keronite
E-MOD (N/m ²)	7.3E10	4.4E10	15.8E10	19.6E10	27.5E10
DENSITY (kg/m ³)	2700	1800	2300	2100	3600
SOS (m/s)	5200	5000	8300	9700	8700
POISSON'S RATIO	0.33	0.35	0.20	0.20	0.30
DAMPING	0.005	0.005	0.005	0.005	0.002
COST	LOW	MED	HIGH	HIGHER	LOW
PERFORMANCE	MED	MED	HIGH	HIGHER	N/A

MODE	FREQUENCY	GENERALIZED	COMPOSITE MODAL
	(Hz)	Mmd	DAMPING
		(g)	
f_0	147	1.55	
f_1	15808		0.002
f_2	21897		0.002

The first three mode shape simulations (natural frequencies) of the Keronite/Mg/Keronite cone are illustrated in **Figs. 5-7**.

Here is a summary of AlBeMet 140 cone-assembly simulation results.

MODE	FREQUENCY	GENERALIZED Mmd
	(Hz)	(g)
f_0	149	1.51
f_1	15806	
f_2	21664	

Here is a summary of AlBeMet 162 cone-assembly simulation results.

MODE	FREQUENCY	GENERALIZED Mmd
	(Hz)	(g)
f_0	150	1.49
f_1	18109	
f_2	25208	

The first three mode shape simulations (natural frequencies) of the single laminate AlBeMet 140 cone are illustrated in **Figs. 8-10**.

For problems such as this in which the boundary conditions and geometry are identical it is safe to assume that the first bending frequency, f_1 is directly proportional to the effective speed of sound in the material (SOS), c_e . I showed this for simple geometries in the March 2006 *Voice Coil* "Assessing High-Performance Diaphragm Materials," www.audioexpress.com/magsdirx/voxcoil/addenda/media/mowry306.pdf.

Remembering that the speed of sound in solid material is the square root of the quotient of elastic modulus, E and the density, ρ ,

$$c = \sqrt{\frac{E}{\rho}} \text{ (m/s),}$$

then it is assumed that the first bending frequency of the cone is directly proportional to the speed of sound within the cone material, $f_1 \propto c$. Using the first bending frequency results from the FEA, f_1 , the effective speed of sound of the coated/sandwich materials, c_e can be calculated based on the results of a single laminate material with identical ge-



FIGURE 5: Piston mode shape of Keronite/Mg/Keronite moving as-sembly at $f_0 = 147\text{Hz}$.



FIGURE 6: First bending mode shape of Keronite/Mg/Keronite cone at $f_1 = 15.8\text{kHz}$.



FIGURE 7: Second bending mode shape of Keronite/Mg/Keronite cone at $f_2 = 21.9\text{kHz}$.

FIGURE 8: Piston mode shape of AlBeMet 140 cone-assembly at $f_0 = 149\text{Hz}$.

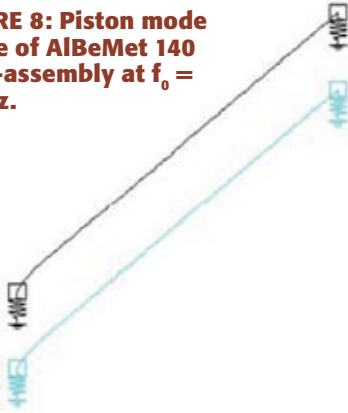
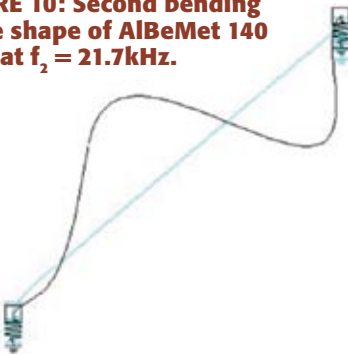


FIGURE 9: First bending mode shape of AlBeMet 140 cone at $f_1 = 15.8\text{kHz}$.



FIGURE 10: Second bending mode shape of AlBeMet 140 cone at $f_2 = 21.7\text{kHz}$.



ometry, in this case AlBeMet 140, where

$$c_e = \frac{8300}{15806} f_1.$$

Then by substituting c_e back into the first relation the lumped or effective composite modulus, E_e , can also be calculated, $E_e = c_{ep}^2$. Then for Keronite coated Mg the speed of sound is equivalent to that of AlBeMet 140, $c_e = 8300\text{m/s}$ and $E_e = 186\text{GPa}$ and $\rho_e = 2700\text{kg/m}^3$! The Keronite coated magnesium is a very high performance material, essentially equivalent in performance to AlBeMet 140 at a much lower cost. The Keronite coated magnesium also has a bit of added composite damping but has a slightly higher density than AlBeMet 140. The mass versus speed of sound can be traded by adjusting the thickness of the Keronite and the related process cycle time. This level of design flexibility is an added feature of Keronite.

If the added mass is not a concern a Keronite/Al/Keronite sandwich cone is another high performance option at a reduced cost. I will simulate that.

MODE	FREQUENCY	GENERALIZED	COMPOSITE MODAL
	(Hz)	Mmd	DAMPING
	(g)		
f_0	145	1.60	
f_1	14978		0.002
f_2	20317		0.002

Here is a summary of a Keronite/AlBeMet 162/Keronite cone-assembly simulation results.

MODE	FREQUENCY	GENERALIZED	COMPOSITE MODAL
	(Hz)	Mmd	DAMPING
	(g)		
f_0	146.5	1.57	
f_1	17999		0.002
f_2	24296		0.002

Here is a summary of a Keronite/AlBeMet 140/Keronite cone-assembly simulation results.

MODE	FREQUENCY	GENERALIZED	COMPOSITE MODAL
	(Hz)	Mmd	DAMPING
	(g)		
f_0	146	1.58	
f_1	17088		0.002
f_2	23045		0.002

Table 2 shows “effective” material properties of Keronite coated metals, 0.03mm/0.06mm/0.03mm sandwiches. These coated alloys are really sandwich composite materials. The lumped material properties listed in **Table 2** can be used in simulations where composite finite elements are not implemented or available.

CONCLUSION

The Keronite process will stiffen an alloy cone. However, the dense ceramic will add some mass and robustness to the cone. The coated magnesium and aluminum cones are true sandwich structures. Amazingly the speed of sound in the resultant structure is higher than the individual substrate

materials except in the case of AlBeMet 162. The elastic modulus of AlBeMet 162 is just too high relative to the Keronite for a “core” material application. This is exactly why the magnesium works so well. The core should be light with a reasonable modulus but lower than the skin material. This is why space-age sandwich composite materials typically use a structural “foam” core with carbon, glass and/or aramid fiber skins all held together with resin that is typically heat cured within an autoclave type device to control material density.

There is an additional feature of these alloy cones coated with Keronite. They are stable, practically inert. They are robust; the surface is very hard. Any issues with the AlBeMet’s health and safety are erased with Keronite. The manufacturing/coating processes are simple, clean, controllable, and repeatable (*Photo 1*). With careful design, cones utilizing the Keronite coating are a serious contender for that small full-range transducer.



PHOTO 1: An automated Keronite coating plant.

The damping is also improved by the Keronite process but only modestly. These ultra high modulus cones still have very little damping but push breakup in a small cone to the last octave of audibility. A coated magnesium cone that performs literally the same as an AlBeMet 140 cone is something to get excited about considering the Keronite/Mg/Keronite cone is approximately 1/10 the cost of the AlBeMet 140!

While on the all-important topic of cost, Keronite International seems to read the minds and meeting needs of the loudspeaker. In April 2006 Keronite International Ltd of Cambridge, UK started volume production in China. Together with strategic business partner ShanHsin Chemical Co Ltd,

TABLE 2 Material properties of coated alloys

MAT 50%-50%	Keronite/Mg/Keronite	Keronite/Al/Keronite	Keronite/140/Keronite	Keronite/162/Keronite
EMOD (N/m ²)	18.6E10	19.6E10	23.7E10	25.5E10
DENSITY (kg/m ³)	2700	3150	2950	2850
SOS (m/s)	8300	7900	9000	9450
POISSON'S RATIO	0.33	0.33	0.3	0.3
DAMPING	0.007	0.007	0.007	0.007
COST	MED	LOW	HIGH	HIGHER
PERFORMANCE	HIGH	HIGH	HIGH	HIGHER

Keronite selected KunShan in JiangSu province as the location for its first surface treatment facility in China. The General Manager of Keronite in China, Connie ChenLu, firmly believes that the new facility will provide the incentives for many more companies to make the switch to Keronite.

“Production in China is essential if we are to deliver our services quickly and cost-effectively. Local companies are becoming more and more demanding but the professionalism of our partners at ShanHsin combined with the infrastructure and state-of-the-art facilities provided by the KunShan Economic & Technological Development Zone gives us confidence that we will satisfy our customers time

after time. This will quickly give us a world-class reputation upon which we can build a strong future for Keronite in China.” For more information on Keronite in China, contact Connie ChenLu at connie.chenlu@keronite.com.cn. 

Steve Mowry, president of SM Audio Engineering, has a BS, Business Administration, from Bryant College, and a BS and MS, Electrical Engineering, from URI with highest distinction. Steve has worked in R&D at BOSE, TC Sounds, EASTTECH, and P.Audio. Steve is currently an independent consultant/lecturer in project management/transducer and system design. His website is www.s-m-audio.com.