

Machining Be

How to safely and effectively machine beryllium (Be).

► BY ALAN RICHTER, MANAGING EDITOR

In theory, a part can be made out of any material, but the part's function, its operating environment and economic considerations dictate which metal to specify. Therefore, when a designer specifies a beryllium (Be) part, there's a very good reason.

The stiff, lightweight metal's unique properties make it the material of choice for an array of tight-tolerance and demanding-environment parts. Machining beryllium, however, can be a high-risk activity—both in terms of the high cost of scrapped parts and the health hazards associated with contracting chronic beryllium disease (CBD).

Nonetheless, machining beryllium safely and profitably is possible with proper housekeeping, good work practices and engineering controls and an understanding of the material's properties and the requirements for cutting it and controlling chips.

Pure as Can Be

When machining high-purity beryllium (material containing about 98 percent Be), the metal tends to be "very mobile and change its configuration," said Alberto Di Bella, president of Florida Precision Aerospace Inc., Deerfield Beach, Fla. "The material acts like it's alive."

Since wall dimensions on many of the beryllium parts the company produces are as thin as 0.090", preventing

the low-fracture-toughness metal from distorting is critical, Di Bella said. To keep a workpiece dimensionally stable, compressed air refrigerated to about 0° F is blown on the cutting tool. Coolant is rarely applied, since beryllium contaminates it. In addition, coolant bubbles can burst and release submicron, potentially hazardous Be particles into the atmosphere.

Florida Precision applies indexable-insert and solid-carbide cutters to machine the metal. The tools have up-sharp edges to prevent rubbing the workpiece. Beryllium chips are more powdery than chip-like, and tool life is shorter than when cutting other difficult-to-machine metals.

In addition to being tough on cutters, Di Bella said machining beryllium puts a lot of stress on the machine tool spindle.

Joseph Crim, applications engineer

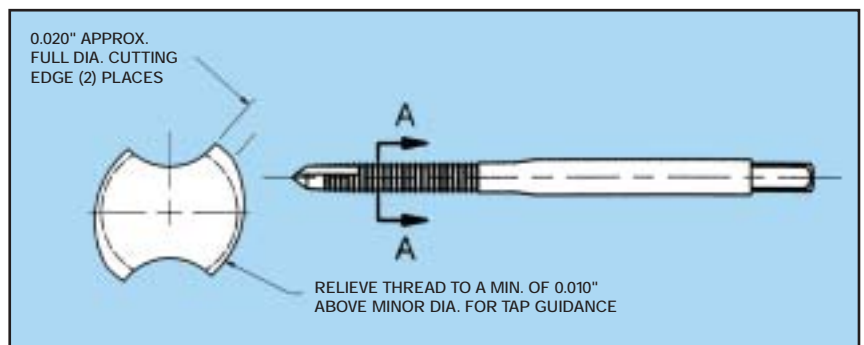
and accounts manager at beryllium producer Brush Wellman Inc.'s Elmore, Ohio, location, said it's important not to remove too much high-purity beryllium in a single pass. Because the material has a low fracture toughness, a heavy depth of cut can cause warping and twinning of the surface. (Twinning is a microtearing of the grain's lattice.)

High-purity beryllium costs about \$2,000/lb., so human error needs to be kept to a minimum to ensure profitability. Therefore, highly skilled machinists are required who can note the changing condition of the tool based on experience.

"You have to calculate the level of risk into what the customer is charged for high-cost parts," Di Bella said.

Tapping a Challenge

With beryllium, every machining op-



Florida Precision Aerospace altered a standard \$3 tap (shown) to increase tool life to 100 holes from three holes with a \$23 tap.

eration has its challenges, but Di Bella called tapping the trickiest. Tapping of blind holes as small as 2-56x0.250" deep needs to be performed manually, and the taps are discarded—not re-ground—when they become dull.

Initially, Florida Precision bought imported taps costing about \$23 each, but tool life was no more than three holes. Concluding that there wasn't any tool specially engineered for tapping high-purity beryllium, Di Bella experimented with different geometries, ground with a manual grinder into stan-

What is beryllium?

Anyone foolish enough to taste beryllium, which is a known carcinogen, would find it tastes sugary, just as early chemists did. Once known as "glucinum," meaning sweet, the element beryllium was found to be present in minerals such as emerald and beryl by a French chemist in 1797 and isolated by two other chemists in 1828.

With a mass of 9.012182 grams for 1 mole, beryllium is atomic number 4 on the periodic table. As a metal, it holds its shape, is extremely light yet quite hard with low fracture toughness, is nonmagnetic and possesses excellent thermal-conductivity properties. Beryllium is—pound for pound—six times stronger than steel and two-thirds the weight of aluminum. The steel-gray, low-density metal melts at 2,349° F and boils at 4,480° F.

High-purity beryllium is used as a moderator in nuclear reactors, as well as for aerospace and defense components. The "mysterious metal" is also alloyed with copper or nickel, with up to 2 percent Be, to improve the properties of the base metal. Beryllium is also mixed with aluminum to form a composite material containing about 40 to 60 percent Be. In addition, a beryllium-oxide ceramic is used as a substrate for printed circuits because of its heat-sink properties.

—A. Richter

dard \$3 taps. He found that by relieving the tap's trailing thread section to a minimum of 0.010" above the minor diameter for tap guidance and leaving 0.020" on the full diameter of the cutting edges, the tool was able to rough-tap over 100 holes. Two other less-modified taps are applied to finish the thread and bottom-tap the thread. In addition to saving money on cutters, tapping time was reduced 67 percent.

In planning a tapping operation into a thin-wall, high-purity beryllium part, Di Bella said it's advisable, whenever possible, to rough the part, leaving stock on both sides for finishing after drilling and tapping. The reason is beryllium tends to bulge and even crack during drilling and tapping if the wall between IDs is too thin. He added that sometimes it's possible to sandwich the contour of a thin beryllium wall between two pieces of hard material, holding them with a C-clamp to prevent the workpiece from bulging while tapping.

Since beryllium chips are dust-like, they clog a hole if not removed. This prevents the tap, especially one with a small diameter, from moving forward or backward and usually causes it to break while in the hole. To avoid breaking taps, Florida Precision blows dry air onto the edge of the hole to keep the cavity clear.

Combined with Copper

Di Bella estimated that about a dozen U.S. companies make parts out of high-purity beryllium, but considerably more machine copper beryllium (CuBe). The CuBe alloy's excellent heat-transfer and current-carrying properties make it desirable to makers of

MACHINING GUIDELINES FOR ALUMINUM-BERYLLIUM ALLOYS

DRILLING

Tool dia. (in.)	Speed (sfm)	Feed (ipr)
< 0.150	100	0.002
0.150 or larger	150	0.003

REAMING

Tool dia. (in.)	Speed (sfm)	Feed (ipr)
< 0.100	50	0.004
0.100 to 0.375	50	0.008
> 0.375	50	0.012

ENDMILLING (SLOTING, FACING)

Tool dia. (in.)	Speed (sfm)	Feed (ipt)
< 0.100	150	0.0004
0.100 to 0.200	200	0.0010
> 0.200	400	0.0040
> 0.200*	800	0.0015

ENDMILLING (PERIPHERAL)

Tool dia. (in.)	Speed (sfm)	Feed (ipt)
< 0.100	200	0.0002
0.100 to 0.200	250	0.0008
> 0.200	300	0.0020

TURNING

DOC (in.)	Speed (sfm)	Feed (ipr)
0.040	350	0.006
0.150	250	0.010

These speeds and feeds are starting-point recommendations. Applying coolant extends cutter life, and peck drilling helps clear chips and lengthens tool life.

*Applying PCD endmills, which are projected to have at least 20 times the life compared to carbide endmills.

Brush Wellman

molds and electrical connectors. One such company is Positronic Industries Inc., a Springfield, Mo.-based manufacturer of small-diameter ($\frac{7}{32}$ " and smaller) electrical connectors.

Tony DiDia, Positronic's automatic-lathe manager, said built-up edge is the biggest problem when machining CuBe with 0.5 percent Be, which is a soft, gummy material prone to poor surface finish. The surface-finish requirements are 63 rms for turned ODs and 32 rms for drilled holes.

Carlos Cruz-Wilson, alloy specialist for National Bronze & Metals Inc., Houston, said his company's CuBe alloy with 0.5 percent Be has a machinabil-

What is chronic beryllium disease?

ity of 50 percent, and the alloy with 1.8 to 2.0 percent Be is harder and has a machinability of 45 percent. (Free-cutting brass has a 100 percent machinability.)

In addition, the copper with 0.5 percent Be has a yield strength of 80,000 to 100,000 psi and a tensile strength of 100,000 to 130,000 psi, while the CuBe with 1.8 to 2.0 percent Be has a yield strength of 140,000 to 150,000 psi and a tensile strength of about 180,000 psi.

“Copper-containing 0.5 percent beryllium is a little more chewy than bronze and the chips are stringy,” Cruz-Wilson said. To control the chips, he suggested applying a cutter with a 3° to 4° rake angle. For machining CuBe with 2.0 percent Be, he recommended selecting a tool made of C-2 carbide with a 2° rake angle. “Never go with a negative rake angle.”

Because any alloy containing beryllium isn't cheap, Positronic reclaims and sells back the chips. Even so, DiDia explained that the goal is to avoid removing too much material, with about 20 percent being turned off.

Since CuBe chips are relatively large and heavy compared to high-purity Be ones, coolant can be applied without worrying about coolant bubbles bursting and releasing submicron particles into the air. Therefore, all turning at Positronic is performed using a universal metalworking oil, which helps with the BUE, DiDia said.

Engineering Controls

Even though CuBe contains up to 2 percent beryllium, that doesn't mean there's only a small possibility workers will be exposed to unsafe levels, said Kathy Creek, a certified industrial hygienist at the Los Alamos (N.M.) National Laboratory. “There have been cases of sensitization and disease among workers who have worked exclusively with a material containing a low percentage of beryllium, such as copper beryllium.”

Beryllium-containing particles must be less than 10µm (0.0005")—a size invisible to the naked eye—to reach the air sacs deep in the lungs, according to Brush Wellman.

DiDia said Positronic has an air-filtration system for its air-conditioned

Chronic beryllium disease (CBD) primarily impacts a person's lungs, possibly causing dry coughing, fatigue, shortness of breath, loss of appetite, fever and night sweats. The disease may develop slowly over a period of many years, causing scarring of the lungs as they become flooded with immune cells attacking beryllium particles lodged in air sacs. This creates an inflammation condition that restricts the exchange of oxygen between the lungs and the bloodstream, which makes breathing difficult and might be misdiagnosed initially as asthma.

To contract CBD, a person first has to become sensitized to the metal. And to become sensitized, which is not an illness or disability, exposure is required. Testing needs to be conducted to determine sensitization.

According to a material safety data

sheet for a beryllium alloy, exposure by inhalation, ingestion and skin contact can occur when altering the material's surface in a manner that generates particulate. This includes grinding, milling, drilling, electrical discharge machining, tapping, turning, reaming, sawing and a number of other machining, cleaning and abrading operations.

For the last 30 years, OSHA has placed limits on the amount of beryllium to which workers can be exposed. OSHA says it's unsafe for workers to be exposed to more than 2µg Be/m³ of air for an 8-hour period, but others maintain that level is too high to adequately protect workers (see main article).

There is no cure for CBD, but early diagnosis and proper treatment can limit its severity.

—A. Richter

plant and electrostatic precipitator units for its machines that cut CuBe. The units collect coolant spray emissions and remove oil smoke and mist before they contaminate the workplace.

Although he said no Positronic employees have been diagnosed with CBD, the manufacturer had a safety consultant conduct air-monitoring tests a couple years ago after workers read reports about the metal's potential harmful effects. The tests examined employee exposure to beryllium while grinding and were conducted by Britney Inc., Springfield, Mo. (“The worst-case scenario is dry grinding on a bench grinder,” DiDia said.)

According to Britney's report, no beryllium was detected in the air sample, but a wipe sample taken on the floor directly below the grinder's left wheel contained 30,800µg/ft.² of beryllium. The report stated that dry sweeping of this area must be prohibited, since it would send beryllium dust into the air that could be hazardous to employees' health. Only wet (damp) sweeping or HEPA vacuuming should be allowed. In addition, the area should

be cleaned after each grinding of CuBe rods, and an N-100-type respirator should be made available to the house-keeping staff.

However, Creek added that an N-type respirator is not resistant to oil. “If one is machining with an oil-based coolant, an N-type respirator cartridge is not advised,” she said. “We use P-type respirator cartridges, which are oil-proof.”

Of course, the engineering controls for machining high-purity beryllium are more elaborate. Because the metal is dry-machined, as much particulate as possible needs to be captured by a device positioned as close as possible to the tool/workpiece interface, explained Scott Salisbury, mechanical engineer with Systems Engineering and Maintenance, Los Alamos National Laboratory (LANL). “The best approach is to capture particulate at the point of generation,” he said.

He added that to capture particulate, air velocity needs to be at least 200 sfm above the cutting speed, which typically starts at 300 sfm. Therefore, a minimum capture velocity of 500 sfm

at the point of generation is suggested.

To determine where to place a capture device, Salisbury said LANL conducts tests machining graphite impregnated with a special die. Chip-wise, graphite behaves similar to beryllium. Using a black light, the path of the die-impregnated particulate can be traced. The machinist should determine the initial placement of the capture device, since he is most familiar with the tool/workpiece interface.

The captured chips are transported through a high-velocity exhaust system. The powdery beryllium particles are first filtered through an 80-percent-efficient centrifugal cyclone separator that collects chips 40µm and larger. The particle stream then passes through a 90-percent-efficient (at 0.5µm) dust collector that captures finer particles. Next, the remaining particle stream passes through the building's 99.97-percent-efficient (at 0.3µm) HEPA filters before being vented into the atmosphere. Air from the building exhaust stack is also monitored to ensure compliance with environmental regulations.

Other safety precautions include hav-

ing personnel wear government-issued clothing that are laundered in the same facility using dedicated equipment and requiring workers to shower before leaving the facility. In addition, workers handling beryllium wear air-sampling pumps, which are analyzed daily.

Exposure Issue

The Occupational Safety and Health Organization says it's unsafe for workers to be exposed to the following atmospheric concentrations of beryllium: more than 2µg Be/m³ of air for an 8-hour time-weighted average, which is the average amount of a substance a person can be exposed to during an 8-hour day; more than 5µg Be/m³ of air for more than 30 minutes or 25µg Be/m³ of air—regardless of the exposure time. (OSHA notes that 2µg Be/m³ of air is equal to about a piece of material the size of a marble pulverized and dispersed into an area 1 mile×1 mile×6'.)

However, many health experts contend that the safe exposure limit is one-



Florida Precision Aerospace



Care must be taken when handling parts made of high-purity beryllium, which is a brittle metal, so features are not chipped or broken.

tenth—or less—of the OSHA requirement. “No one actively working with beryllium is sticking to the OSHA level,” said John Martyny, associate professor and industrial hygienist at the National Jewish Medical and Research Center, Denver. “That level is not protective enough.”

Chronic beryllium disease is an allergic disease, and only a percentage of the population has a propensity to become allergic, but the dose, or exposure level, plays a significant role. Martyny predicted that if a company oper-

MACHINING AND CUTTER GUIDELINES FOR BERYLLIUM-COPPER ALLOYS

TURNING

Be content (%)	Speed (sfm)	Feed (ipr)	Back Rake (°)	Side Rake (°)	Relief (°)	Nose Radius (in.)
1.8-2.0	1,000-1,200	0.010-0.020	0-10	10	5	0.032
0.5 max.	1,500-1,900	0.015-0.030	0	5	5	0.030

MILLING

Be content (%)	Speed (sfm)	Feed (ipt)	DOC (in.)	WOC (in.)	Helix (°)
1.8-2.0	150-200	0.001-0.003	0.060-0.130	0.5	25-35
0.5 max.	500-900	0.006-0.010	0.060-0.130	0.5	25-35

DRILLING WITH HSS TOOLS

Be content (%)	Speed (sfm)	Feed (ipr)	Helix (°)	Point Angle (°)	Lip Relief (°)
1.8-2.0	150-350	0.003-0.010	30	120	13
0.5 max.	200-600	0.002-0.006	30	120	13

TAPPING

Be content (%)	Speed (sfm)	Rake (°)	Point Shape	Flutes
1.8-2.0	15-25	8	spiral	2, 3, 4
0.5 max.	15-120	8	spiral	2, 3, 4

REAMING

Be content (%)	Speed (sfm)	Feed (ipr)	Margin (in.)	Chamfer (°)	Chamfer Relief (°)	Radial Rake (°)
1.8-2.0	60-120	0.003-0.015	0.015	45	6-10	5-10
0.5 max.	130-600	0.002-0.015	0.015	35-60	5-10	5-10

ated within OSHA's exposure level, 15 to 20 percent of the employees who work with beryllium would eventually contract CBD.

"We suggest that enough air samples be taken to be 95 percent confident that exposure levels to beryllium are consistently below $0.2\mu\text{g}/\text{m}^3$ of air per 8-hour period," Martyny said. He recommended that workers exposed to concentrations greater than that wear respirators.

LANL's Creek said the complex where she works strives to achieve the lowest practical level, which for the most part is below the detection level of $0.02\mu\text{g}$ of Be/m^3 of air for an 8-hour period. She noted that ultrafine particles $0.1\mu\text{m}$ and smaller present the highest risk. "You don't just breathe in and out submicron particles," she said. "Many of the ultrafine particles a person breathes are desposited in the lungs."


In solid form and as contained in finished products, beryllium and beryllium-containing materials pose no special

health risk, said Brush Wellman's Crim. He noted, though, that like many industrial materials, beryllium and beryllium-containing materials might present a health risk if handled improperly.

Nonetheless, Creek recommended avoiding skin contact with objects containing beryllium. "It is a hypothesis that exposure to $1\mu\text{m}$ and smaller particles combined with movement of the skin could result in penetration of these particles into a live layer of skin," she explained. "We are considering the possibility that a person may become sensitized through skin exposure."

Creek advised keeping beryllium off of the skin by effective means such as protective clothing, gloves, hand washing and showering. She also recommended working with someone who knows the metal.

"My primary recommendation is that if a company is machining beryllium metal, an oxide or an alloy, they hire a consultant who has effectively con-

trolled sensitization for beryllium operations," she said. 

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