MATERION

TECH BRIEF

Machinability of Emery Low Lead (C17210) Alloy Rod

Emery Low Lead™ alloy is a new, RoHS-compliant copper-beryllium alloy rod and wire that delivers comparable machinability to high-performance lead-containing materials.

Emery Low Lead alloy's mechanical and electrical properties are identical to C17200 (Alloy 25) CuBe2 and C17300 (Alloy M25) CuBe2Pb, while providing machinability that closely matches the performance of lead-containing M25.

Safety Notes

It is important to follow all necessary safety precautions when machining, heat treating or cleaning with solvents. Use the proper personal protective equipment and follow all guidance on Materion's Safety Data Sheets for all substances involved.

ROHS EXEMPTION 6(C)

Lead (Pb) is naturally found in the ores that are mined to produce copper alloys. It is extremely difficult to refine copper to the point where all the lead is removed; there will always be some lead remaining as an impurity in copper alloys. The Copper Development Association assigns UNS numbers for different copper alloy compositions and these are published on unscopperalloys.org. A quick review of the published compositions of alloys where lead is not intentionally added shows that small amounts of lead are naturally present in most copper alloys as an impurity. For this reason, the RoHS regulations consider copper alloys with less than 0.1% lead (1000 ppm) to be lead-free.

The European RoHS regulation restricts the use of certain substances including lead in electrical and electronic equipment (EEE). However, Exemption 6(c) of Annex III allows for up to 4% lead by weight to be added to copper alloy rod and wire to improve machinability in automatic screw machining processes. The current Exemption 6(c) is set to expire 30 June 2027.

The European Commission (EC) launched a new review in 2024 to decide on whether to extend RoHS Exemption 6(c). While a decision is not expected until early 2026, a renewal would permit the use of lead in copper alloys for another 4 years. A rejection would trigger a 12- to 18-month transition period, allowing the industry to find alternatives to lead-containing copper alloys.

ALLOYS 25 AND M25 COPPER-BERYLLIUM ROD AND WIRE

Alloy 25 is a copper-beryllium alloy that features the highest strength available in copper alloys while still retaining 22-30% of the conductivity of pure copper. This alloy also has high fatigue strength, good corrosion resistance and excellent resistance to stress relaxation. These attributes make it ideal for use as contacts in high-reliability, miniature electrical and electronic connectors. While its mechanical and electrical properties are excellent, the Copper Development Association classifies its machinability as only 20% (of free-cutting brass), which the industry considers insufficient for high volume machined connector applications.

Alloy M25 has physical and mechanical properties identical to Alloy 25. It has 0.2-0.6% lead added. M25 has a machinability rating of 50% of free-cutting brass, making it suitable for high-volume production in automatic Swiss screw machines. M25 is commonly used for semiconductor test probes and for the female socket contact in high frequency and RF connectors, such as coaxial connectors, MIL-Spec connectors and FAKRA connectors.

Without added lead, Alloy 25 has insufficient machinability to produce such high-volume connectors in an economical fashion. Recognizing the need for a more machinable, high-strength copper-beryllium alloy without the added lead content, Materion developed a new alloy to fill this void.

DEVELOPMENT OF EMERY LOW LEAD ALLOY

Materion evaluated numerous potential compositions for optimum performance. Each candidate material had micro-alloying elements added to try to greatly improve machinability compared to standard Alloy 25. RWTH Aachen University was enlisted to conduct initial machinability trials of the candidate materials using their existing machinability index. Based on the results of these trials, a final composition was selected for further development.

The chosen material was supplied to several customers for machinability trials in their existing Swiss screw machines, including the production of real parts requiring turning, slotting, knurling, plating, etc. It was understood that minor tool adjustments would likely be necessary to achieve the best machinability results. The findings are presented below.

EVALUATION OF MACHINABILITY

Machinability has always been difficult to define using a singular parameter. The machinability of a given alloy depends on factors such as operation type, tool geometry, tooling type, process speeds, etc., and can vary across equipment types. Hence, a general machinability rating provides the designer with rough machinability guidelines, but typically requires adjustments to obtain optimal machinability.

Machinability can be defined in different ways. Some possibilities include:

- Parts produced per hour
- Tool wear/tool life
- Cutting force required
- Surface finish capability
- Dimensional tolerance capabililty

ASTM E618 “Standard Test Method for Evaluating Machining Performance of Ferrous Metals Using an Automatic Screw/Bar Machine” provides a procedure to evaluate machinability and forms the basis of the Copper Development Association’s machinability index. Machinability test specimens such as those shown in Figure 1 are machined in automatic screw machines out of 25.4 mm (1 inch) diameter rod. The machining speeds and feeds are adjusted to find the combination that provides a tool life of eight hours. Tool life is measured by the length of time in which the test pieces produced are within dimensional and surface roughness tolerances. The maximum number of pieces produced per hour at a tool life of eight hours becomes the machinability rating and is expressed as a percentage of the number of pieces produced per hour by C36000 (CuZn37Pb) free-cutting brass, the most machinable copper alloy.

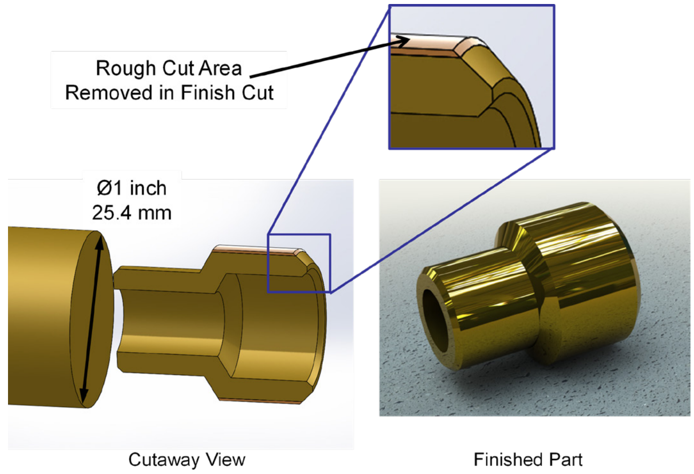

Figure 1: Standard ASTM E618 machinability test specimen.

The general geometry of standard ASTM E168 test specimens are rough cut and a finishing cut removes the indicated area. The ratio of the number of in-tolerance parts produced from a given alloy relative to the number of in-tolerance parts produced from free machining brass (C36000) CuZn37Pb is the machinability rating for that material.

The strength of this method is that it yields a machinability rating that is directly tied to production rate (number of parts per shift), with optimum tool life. However, the test requires the machining of dozens to hundreds of rods to obtain the rating. It is useful as a one-time trial to establish a machinability rating but is completely impractical as a quality-control measure. Note that ASTM International withdrew this standard in 2023. Table 1 compares the machinability of Alloy M25 and Alloy 25 with other machinable leaded copper alloys.

Table 1: ASTM E618 Machinability Rating for Some Common Leaded Copper Connector Alloys

Alloy and Temper	ISO Designation	Lead (Pb) Content	ASTM E618 Machinability Rating
C17300 M25 HT	CuBe2Pb	0.2-0.6%	50%
C19150 HT	CuNi1Pb1P	0.8-1.2%	75%
C36000 ½ H	CuZn37Pb3	2.5-3%	100%
C54000 H	CuSn4Pb-4Zn3P	3-4%	80%
C17200 HT	CuBe2	-	20%

ISO 3685 "Tool-life testing with single-point turning tools" is another means to evaluate tool life. This standard specifies the tool material, tool geometry and cutting fluid. It requires the use of multiple cutting conditions (speeds, feeds, depth of cut, etc.).

The machining process is periodically stopped and the wear measured at specific points on the tool. The tool wear vs. cutting times under multiple conditions is plotted. The test also determines how much tool wear can be tolerated before produced parts are out of specification. With these data points, one can optimize the cutting conditions (tool materials, machine settings) to get the best balance of tool life and production speed.

ISO 3685 also contains a table in the Appendices that describes the shape of machining chips. You can determine which chips are acceptable for your particular machining operation and only use materials and cutting operations that create those style chips.

Caveats on Machinability Ratings

Machinability and machinability ratings are not universal. Material that works well for one machining operation can fail during another. Many factors influence machinability.

Material factors:

- Temper and hardness
- Surface finish
- Straightness
- Residual stress
- Grain size
- Lead content
- Toughness and ductility
- Material tendency to work harden

Machine factors:

- Individual machine
- Machine type (CNC, cam-driven)
- Tool material type, hardness, shape, sharpness, chip-breaking capability
- Tool wear
- Feeds, speeds, and depth of cut
- Operator skill/familiarity with machine
- Lubricant/coolant type, cleanliness and amount
- How well the rod/wire is centered on the lathe
- How the material is fixtured/chucked
- Amount of vibration
- Heat generated during machining

Final part configuration:

- Shape and size
- Dimensional tolerance requirements
- Surface finish requirements
- Amount of material removed
- Required heat treatment and potential distortion

Particular machining operations:

- Turning
- Drilling
- Grinding
- Sawing/slotting
- Knurling
- Etc.

RESULTS OF MACHINABILITY TRIALS

Materion supplied RWTH Aachen University with samples of five candidate materials and standard M25 alloy as a control. These 40 mm (1.575") diameter rods were evaluated using their existing machinability testing equipment. The candidate materials were rated with a machinability index from 0 to 100 on 4 criteria: chip shape, tool wear, required cutting force and roughness of machined surfaces. The chips from Emery Low Lead alloy were comparable to those of M25, as shown in Figure 2.

Figure 2: Chips from M25 (left) and Emery Low Lead (right) alloys are both ranked with a chip shape index of 80.

The surface finish of the Emery Low Lead alloy was also comparable to standard M25 alloy, as was the required cutting force, as described in Table 2. Tool wear was similar for the two materials, as shown in Figure 3.

Table 2: Results of Surface Roughness and Cutting Force Tests

Material	Ra (μm)	Rz (μm)	Cutting Force (N)
M25	0.581	4.10	180.7
Emery Low Lead Alloy	0.245	2.10	190.9

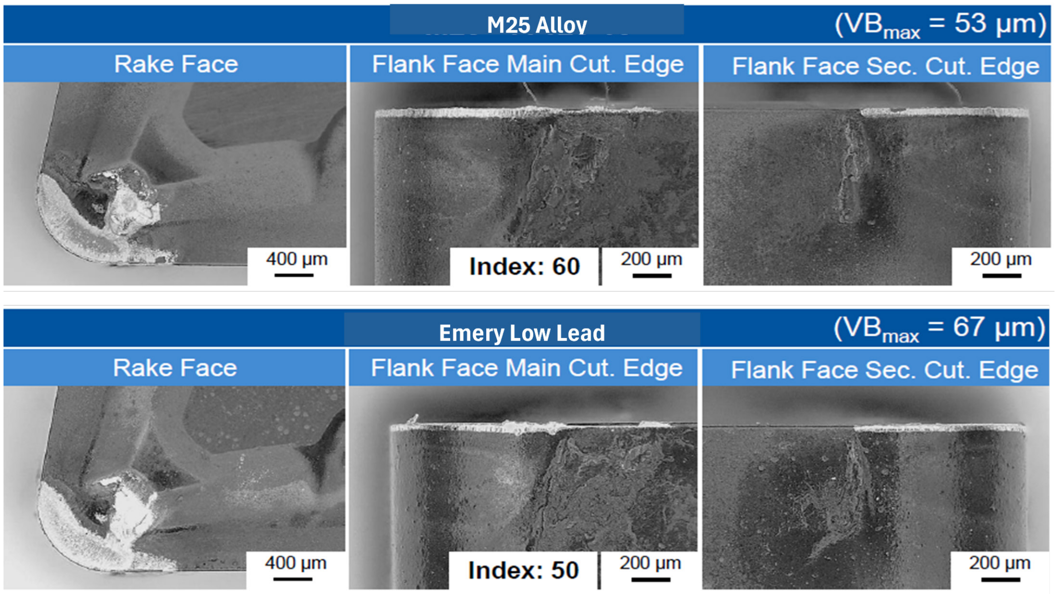

Figure 3. Results of tool wear tests.

At the smallest diameter (1.52 mm/0.060”), Emery Low Lead alloy ran successfully on cam-driven Swiss screw machines without adjustments to machining practices (speeds, feeds, etc.). This included turning, drilling, cross-drilling and sawing. At this size and under these machining conditions, the material machined the same as M25 with no adjustments required.

As the diameter increased, additional tool setting adjustments were needed. For 4 mm (0.156”) diameter, machinists had to use slower speeds and reduced feeds compared to the settings typically used for M25. While the chips were different, they were still deemed to be acceptable.

RWTH Aachen assigned a machinability index for each of the four categories to the trial materials and compared them to standard M25 alloy. The results are shown in Table 3.

Table 3: Machinability Indices Across All Four Criteria

Material	Chip Shape Index	Surface Roughness Index	Cutting Force Index	Tool Wear Index
M25	80	90	70	60
Emery Low Lead Alloy	80	100	70	50

Based on the results of the machinability studies at RWTH Aachen, Materion down-selected the final chemistry for additional trials at specific machine shops and connector manufacturers. These locations featured a variety of different screw machines, including CNC and cam-driven machines. Additionally, each trial customer used the material to duplicate parts that they routinely make with M25, which allowed for direct comparison to M25. The results are tabulated in Table 4.

Tool settings and necessary parameter adjustments for successful machining at 10 mm diameters are currently being validated. The confirmed results will be documented in this report in the near future.

Applicability of Machinability Data

Every machining operation is different. Every machine is different. The data presented here provide a good starting point for machining Emery Low Lead material. You may need to adjust your tooling, speeds or feeds to obtain the full benefit of this material, especially at diameters above 4 mm (0.156”).

Heat Treating Emery Low Lead Alloy

Emery low lead material responds to heat treatment similarly to Alloys 25 and M25.

Plating Emery Low Lead Alloy

Emery low lead material can be plated similarly to Alloys 25 and M25.

SUMMARY

Emery low lead is a new machinable, high-performance, RoHS-compliant material available in rod and wire. It may be used in place of lead-containing M25 alloy, with some minimal adjustments to machining practices in order to obtain comparable machinability.

Table 4: Summary of Machining Trials at RTWH Aachen, Commercial Machine Shops and Connector Customers

Diameter inches (mm)	Test Outcome	Customer	Machine Operation	Machine
0.060 (1.52)	Drop-in for M25	North American machine shop 1	Turning	Cam Swiss screw
0.060 (1.52)	Drop-in for M25	North American connector manufacturer 1	Turning, drilling, cross-drilling and sawing	Cam Swiss screw
0.098 (2.50)	Drop-in for M25	European connector manufacturer	Turning, drilling and knurling	
0.156 (3.96)	Needed slower speeds (7600 rpm to 5000 rpm) and feeds (6.05 PPM to 5.0 PPM) relative to M25 Good chips created, still concerns with surface finish	North American machine shop 1	Turning	Cam Swiss screw
0.156 (3.96)	Run as M25 drop-in Chips less favorable than M25 chips - coarser morphology, firmer feel Dimensions and burr same as M25	North American connector manufacturer 1	Turning, drilling, cross-drilling and sawing	CNC Swiss screw
0.156 (3.96)	Need some modifications to the screw-machining strategy and order of operations Basic feeds and speeds would not require major change and productivity was not expected to be negatively impacted	North American machine shop 2	Turning, drilling	Swiss screw
0.156 (3.96)	Need significant changes to approach strategy, and/or tooling to CNC machine Outcome not considered to be a permanent barrier to future work	North American machine shop 2	Turning, drilling, slotting and crimping	CNC
0.156 (3.96)	Run as M25 drop-in Chips on the longer/larger side but no issues observed Dimensions and burr same as M25	North American connector manufacturer 2	Turning, drilling	CNC Swiss screw
0.394 (10.0)	Parameter adjustments required to find best chip and surface Sufficient machinability to warrant further study	European connector manufacturer	Turning, drilling and slotting	CNC Swiss screw
1.5748 (40.0)	Very similar to M25 Slightly worse tool wear, slightly better surface finish	RWTH Aachen	External longitudinal turning	CNC lathe

Materion Global Headquarters
6070 Parkland Boulevard
Mayfield Heights, OH 44124
USA

connect@materion.com
+ 1 800.375.4205 (+1.216.383.6800)
TB-AM-663