Engineering Guide:
ToughMet ® 3AT (C72900)
ToughMet ® 3CX (C96900)

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Introduction

A review of the material properties of Brush Wellman's ToughMet® 3AT and ToughMet® 3CX is presented. ToughMet® 3AT is a wrought, spinodally hardened copper alloy with UNS C72900. It is specified in AMS 4596. ToughMet® 3CX is a continuously cast, spinodally hardened copper alloy with UNS C96900. It is specified in ASTM B505-96. ToughMet® is a high strength copper alloy capable of yield strength exceeding 100 ksi. Its high strength and low coefficient of friction make it well suited for use as a bushing and bearing material. It also out-performs many copper alloys and nickel alloys in corrosive environments.

ToughMet® requires a high degree of uniformity of composition and microstructure at the beginning. A casting technology for this alloy system has broken through the barriers of conventional static or continuous casting methods by enabling sizes up to about 25 inches in diameter in single lot quantities as large as 15 tons. This patented technology, EquaCast™, enables uniformity of composition and microstructure for an alloy system with a freezing range as large as 250F. The key to this closed-head casting technology is a patented top cap with directed slots interposed between the top of the mold package and the liquid in the large holding furnace. Cyclic withdrawal of the billet at high rates of speed creates high speed planar jets of molten metal which penetrate the solidification zone. This action breaks dendrites, creates seeds for refinement and makes the solidification process and resultant microstructure very uniform and equiaxed. Segregation-prone alloys such as in ToughMet®'s CuNiSn system are otherwise rendered hot short during hot working or highly variable in finished mechanical properties both in cast and wrought products. This breakthrough is enabling for a new spectrum of applications for these non-strip high performance materials. Also, significant achievements in shape casting are available when the EquaCast™ concepts are combined with shaped molds.

The data presented in this report are believed to be reliable. However, some of these data are derived from isolated tests on a limited numbers of samples and may not be representative of available material. Brush Wellman assumes no responsibility for damages incurred from the use of the information contained herein.

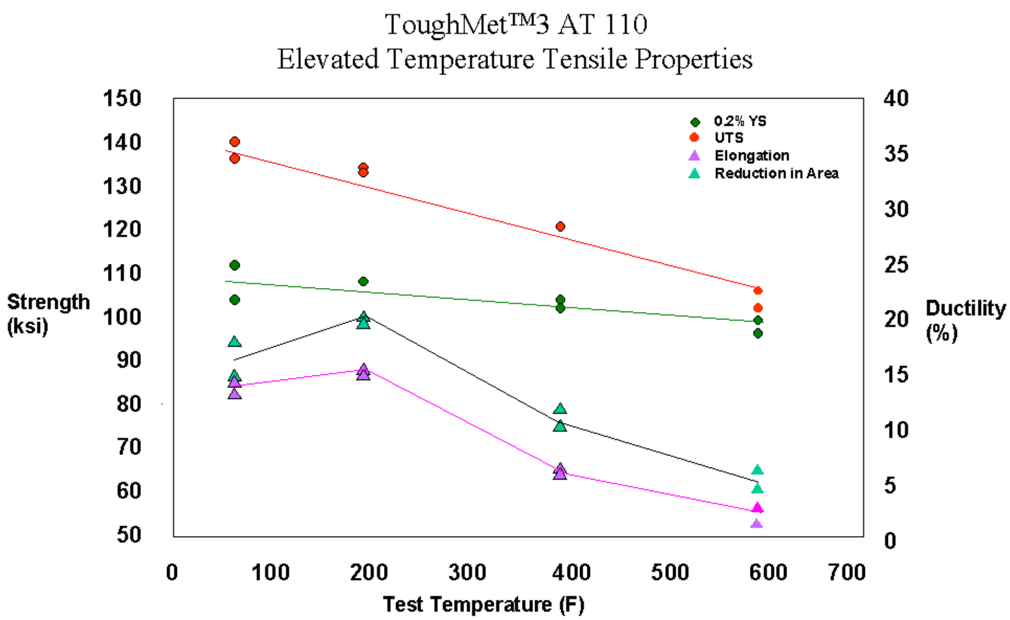
ToughMet® Data

Minimum Mechanical Properties of Standard ToughMet® Alloys and Tempers

Alloy	Description	Temper	Outside Diameter (in.)	Yield Strength (0.2%, ksi)	Tensile Strength (ksi)	Elongation (%)	Hardness (Rockwell)
ToughMet® 3 CX	Cast and Spinodally Hardened	T3CX90	All Sizes	90	105	6	HRC 27
		T3CX105 (ASTM B505)	Under 4”	105	110	4	HRC 30
			4”+	94.5	99	4	HRC 30
ToughMet® 3 AT	Wrought and Spinodally Hardened	T3AT90	Under 4”	90	110	15	HRC 22
			4”+	90	110	12	HRC 22
		T3AT110	Under 4”	110	125	10	HRC 30
			4”+	110	125	6	HRC 30
		T3AT120	Under 4”	120	135	7	HRC 32
			4”+	120	135	4	HRC 32

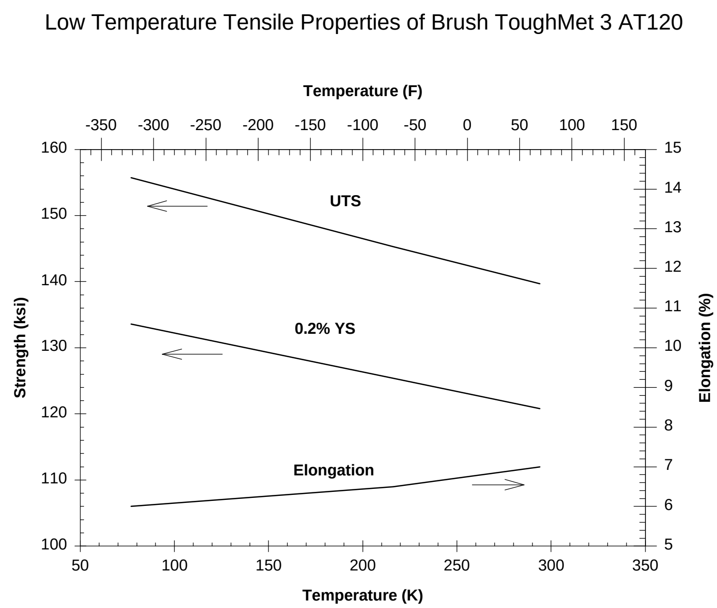
Other Tensile Properties

Elevated Temperature Tensile Properties



The testing was performed per ASTM E21 using a 1.0" gauge length, 0.25"diameter tensile bar (4D gauge length).

Low Temperature Tensile Data



The testing was performed per ASTM E8 using a 1.0" gauge length, 0.25"diameter tensile bar (4D gauge length).

Compressive Strength

Below, the compressive strength of three heats of ToughMet® 3 is shown. Both wrought and cast material is represented.

Room Temperature Compression Strength Values for ToughMet® 3 Tempers

(ASTM E9-89a (1995), 0.0050 in./in./min)

Sample ID	0.2% Offset (ksi)	0.2% Average (ksi)	Modulus (10^6 psi)	Modulus Average (10^6 psi)
T3AT90	121 131 128	126.7	20.9 20.8 19.7	20.5
T3AT 110	130 130 132	130.7	20.7 20.7 20.8	20.7
T3CX105	116 116 119	117.0	20.5 20.4 20.5	20.5

Shear Strength

ToughMet® 3 has been tested per MIL 1312-13. Double shear testing was performed per sample heat.

Temper	Shear Strength(ksi)
T3AT90	75.8
T3AT110	81
T3CX105	75

Pin Bearing Tests

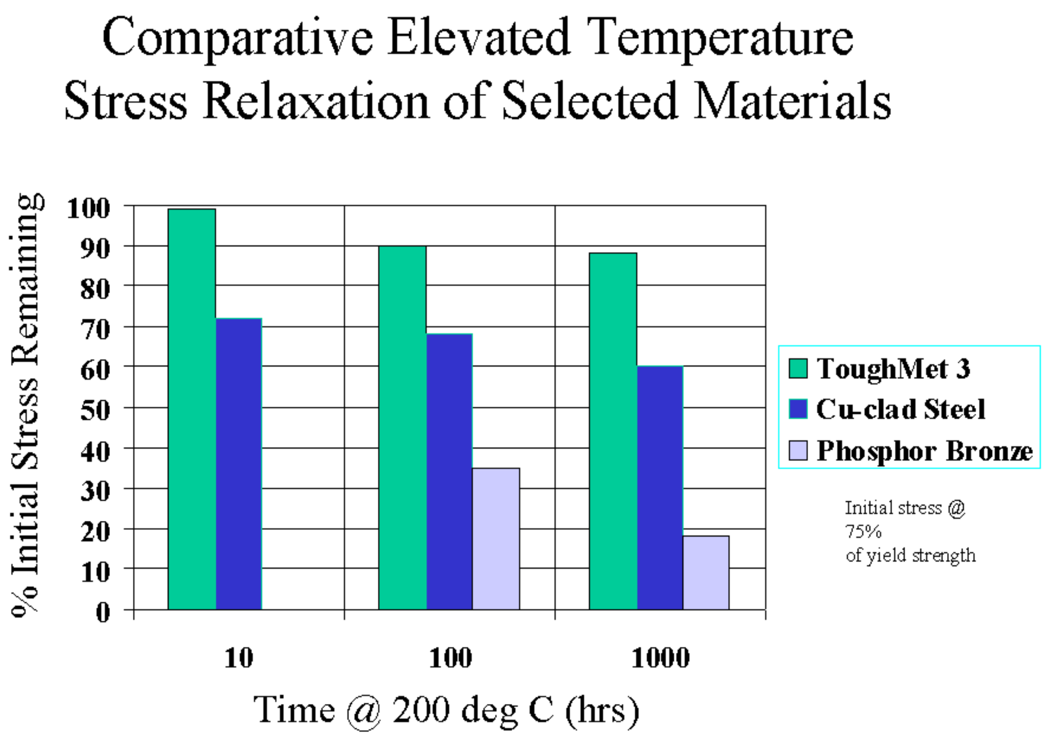
Below are the results of the pin bearing test per ASTM E238-84 (1996).

Statistics of Pin Bearing Tests on Brush ToughMet® 3 (e/D=1.5)

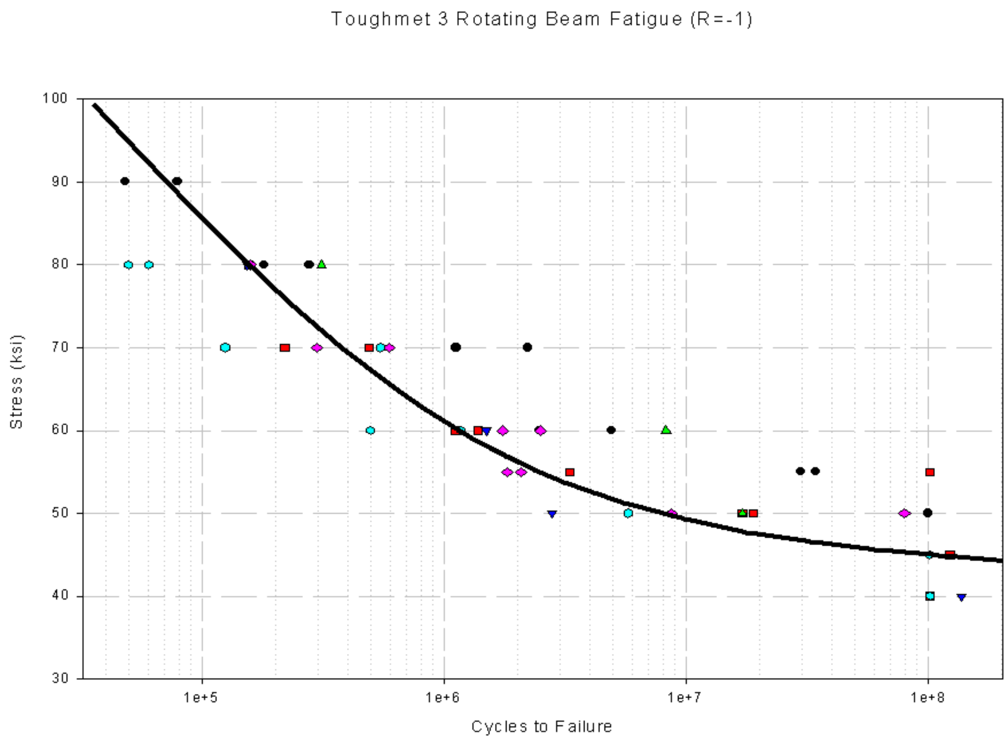
ASTM E238-84 (1996)

Sample ID	Average Bearing Yield Strength (ksi)	Standard Deviation Yield Strength	Average Bearing Ultimate Strength (ksi)	Standard Deviation Ultimate Strength
T3AT90	171.2	2.14	214.0	2.71
T3AT 110	190.7	2.28	236.4	2.23

Stress Relaxation



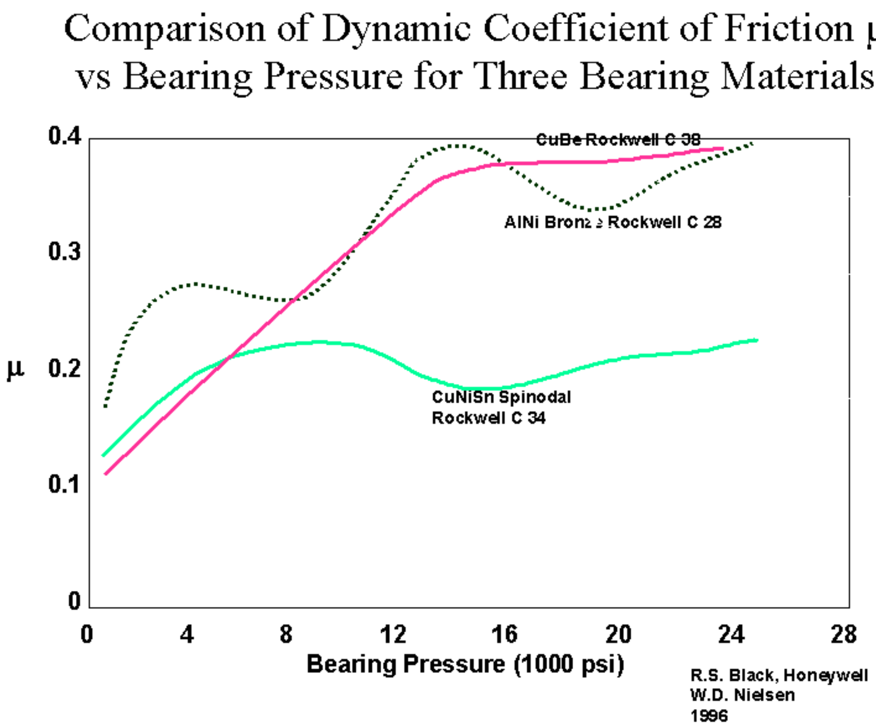
Rotating-beam Fatigue



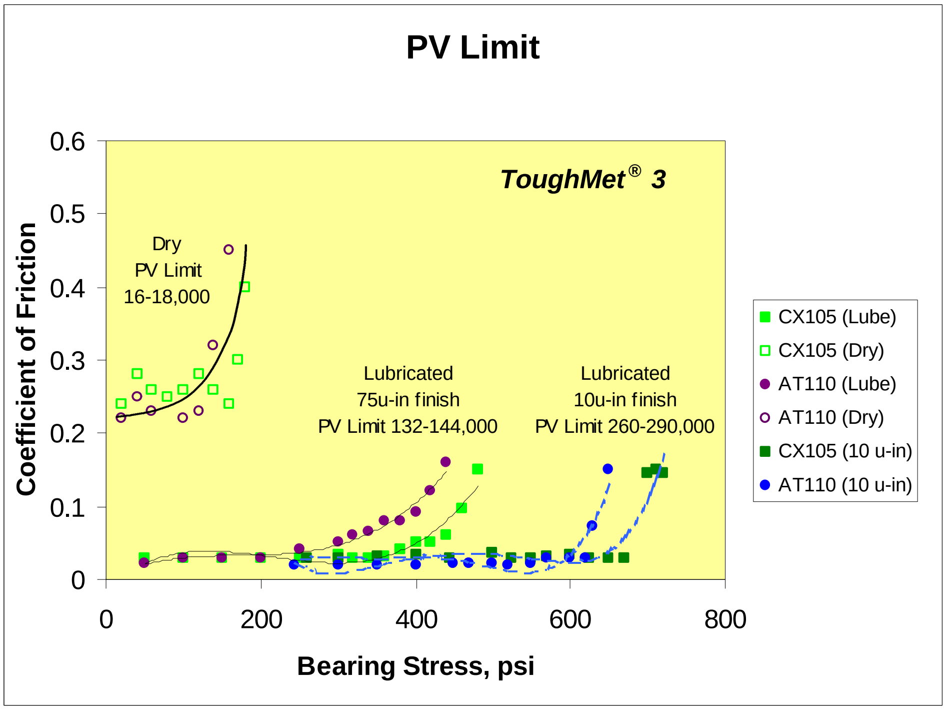
This testing was performed on ToughMet® 3AT tubing with 105 ksi yield strength.

Dynamic Friction

Coefficient of Friction versus Applied Load



Above results are for lubricated bushings using Aeroshell 22 grease with oscillating motion (10 Hz). ToughMet® 3 is labelled as CuNiSn spinodal.



These tests were performed with 1" plain bearings moving at a speed of 300-400 surface feet per minute. The shaft was 1 inch diameter hardened steel (HRC 60). The lubricant was SAE 10 W HD. *("ToughMet® Plain Bearings --Performance with High PV" , BWI-AT0050/02)*

PV Limit Comparison

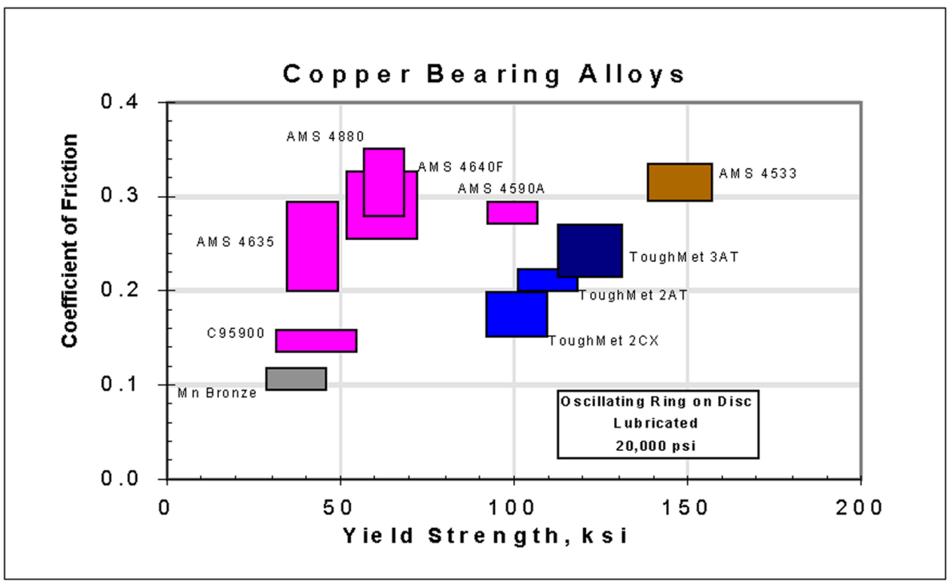
PV Limit Comparisons

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

Comparison data from Bunting Bearing Corp.

The basic testing apparatus for determining the PV Limit is a 1 inch diameter shaft of hardened steel (HRC 60) fitted with a plain bearing of nominal 1 inch ID x 1 inch long. The test was run at constant rotational speed with incremental loading to the bearing. *("ToughMet® Plain Bearings --Performance with High PV ", BWI-AT0050/02)*

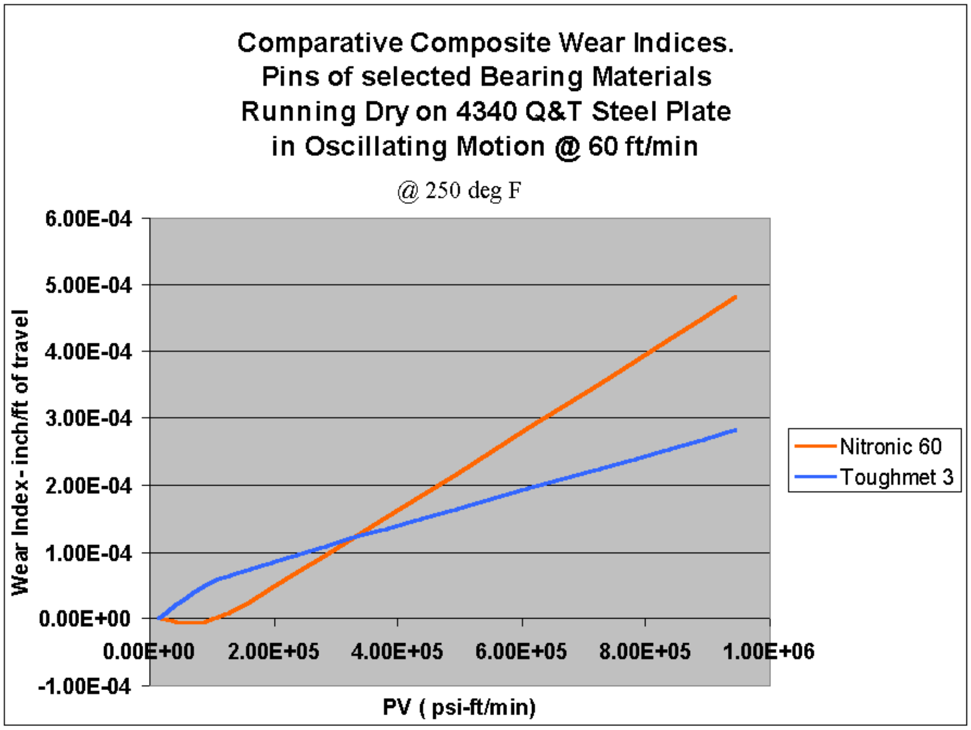
Coefficient of Friction versus Material Strength



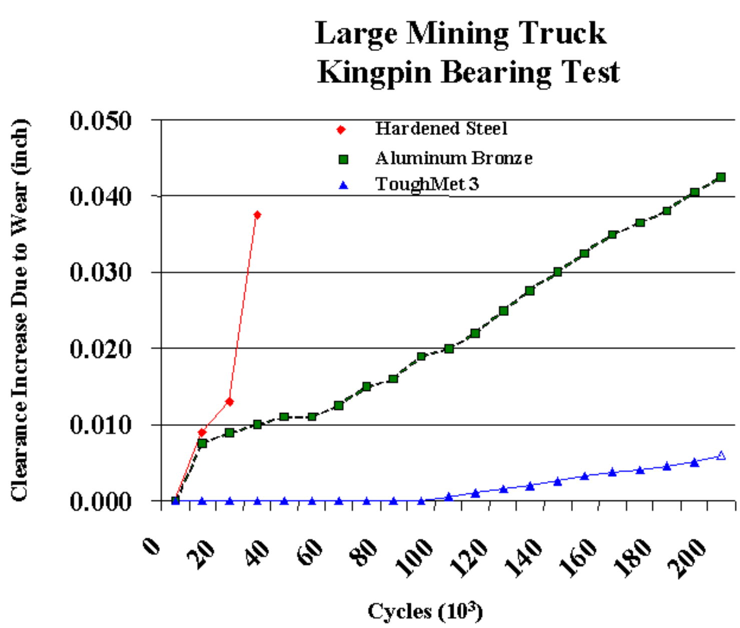
The above data were obtained from a test utilizing small hollow cylinders machined from rods of the respective copper alloys. These test specimens were end-loaded onto chrome plated (QQC-C-320) discs of 4140 heat treated to HRC 53, typical of many aerospace applications. This "Ring on Disc" test utilized liberal amounts of AeroShell 33 grease at the start of the ± 45 degree, 4.3 Hz rotational oscillation of the specimen. The loading was maintained at 20,000 psi (~3 Mpa) on the ~ 10 microinch finishes of the mating surfaces. Peak relative motion was at a speed of 10 inch/s (250 mm/s). *("Anti-Friction Behavior of Selected Copper-Based Bearing Alloys," BWI-AT0023)*

Wear Performance

Pin Wear Tests



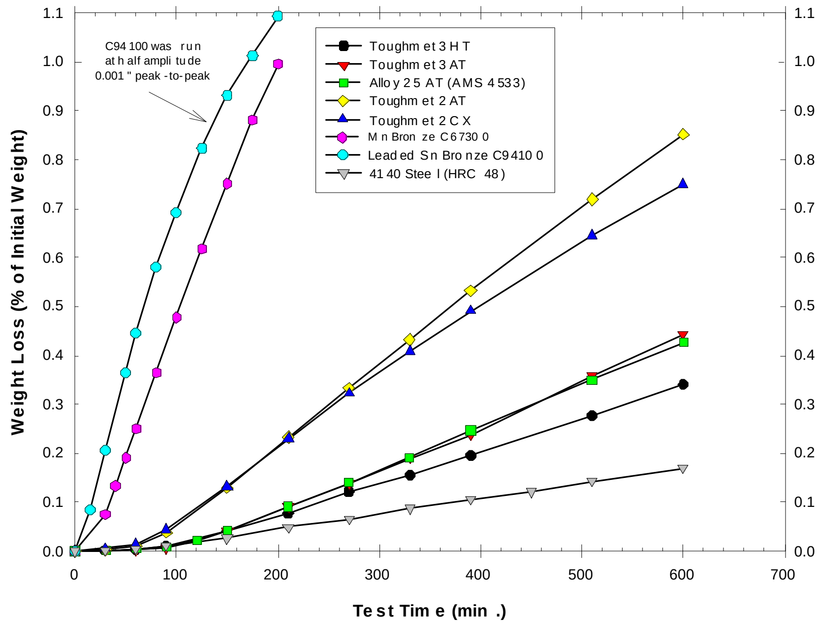
Plain Bearing Wear Tests



Oscillating motion over 45 deg. Bearing stress 2000 psi.

This test consisted of slowly rotating a 3.5 inch diameter, 2.5 inch long plain bearing back and forth 45 degrees around an HRC 60 steel kingpin. The temper of the ToughMet® was T3CX105.

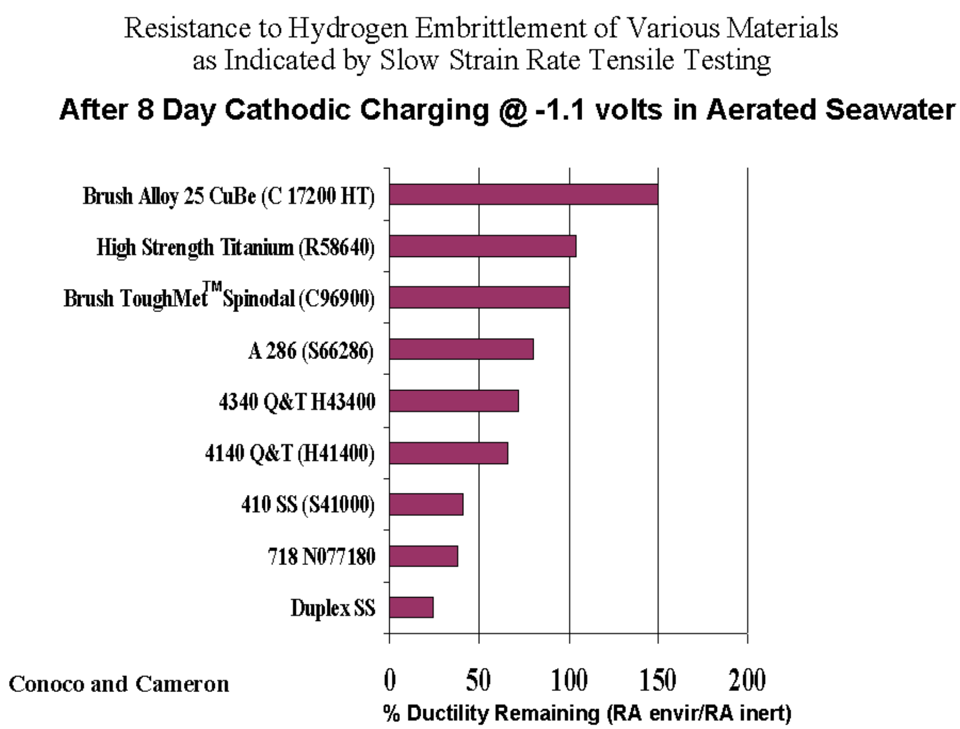
Cavitation Performance



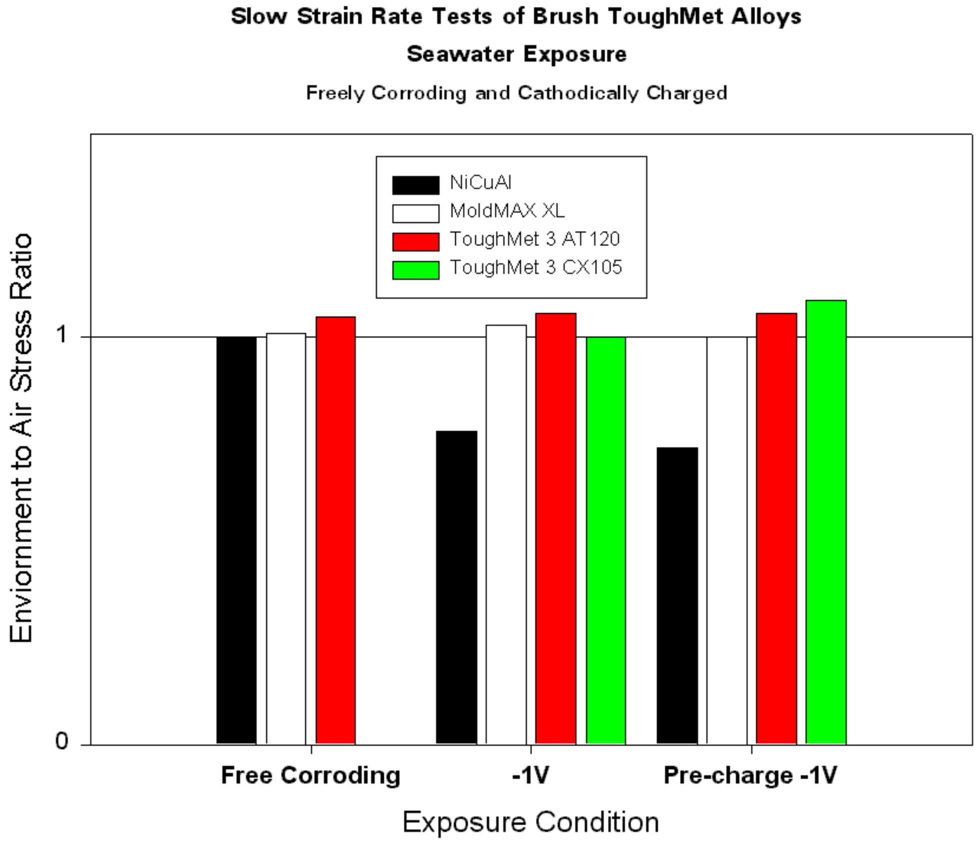
These results were obtained per ASTM G32, "Cavitation Erosion Using Vibratory Apparatus," which subjects a metal to cavitation in deionized water. This method is often used as a screening test to compare metal erosion from cavitation damage in a controlled environment. External factors such as dissolved 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. *("Cavitation Resistance of Selected Copper Alloys," BWI-AT0026)*

Corrosion Studies

Hydrogen Embrittlement

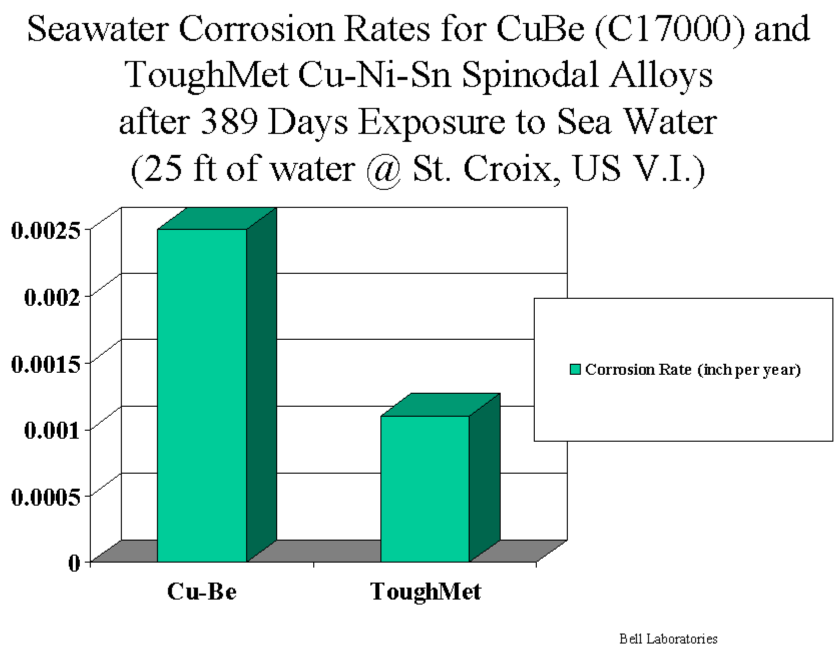


Cathodic Protection

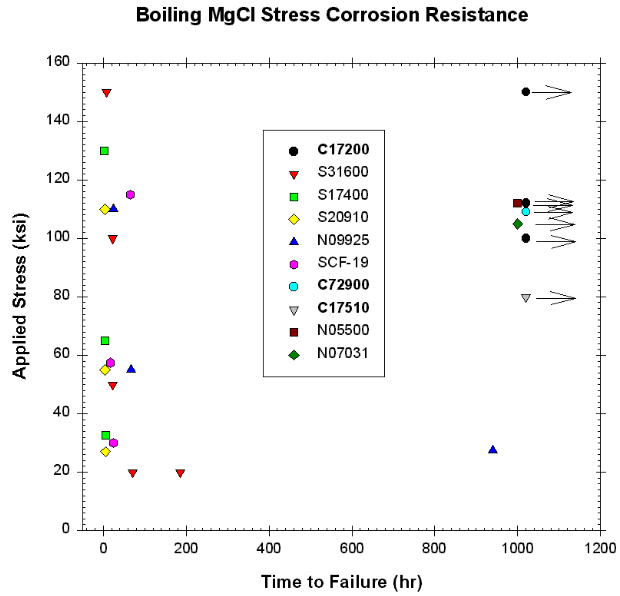


ToughMet® was tested at the Naval Surface Warfare Center to examine the alloy's response in cathodically protected situations in seawater. The results of these tests (see above) show that ToughMet® is unaffected by either seawater exposure or hydrogen embrittlement.

Seawater Corrosion

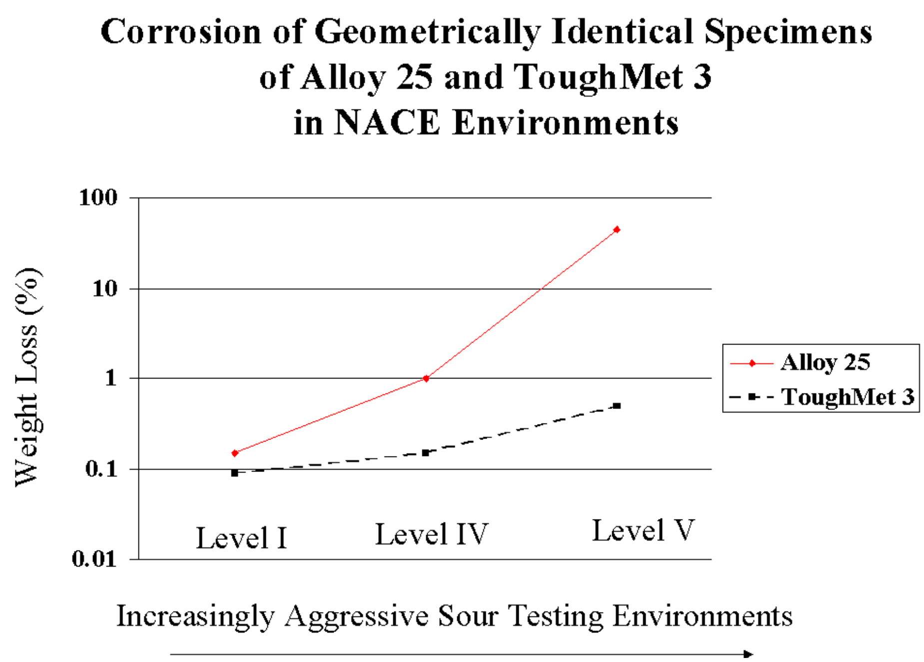


Chloride Stress Corrosion Cracking



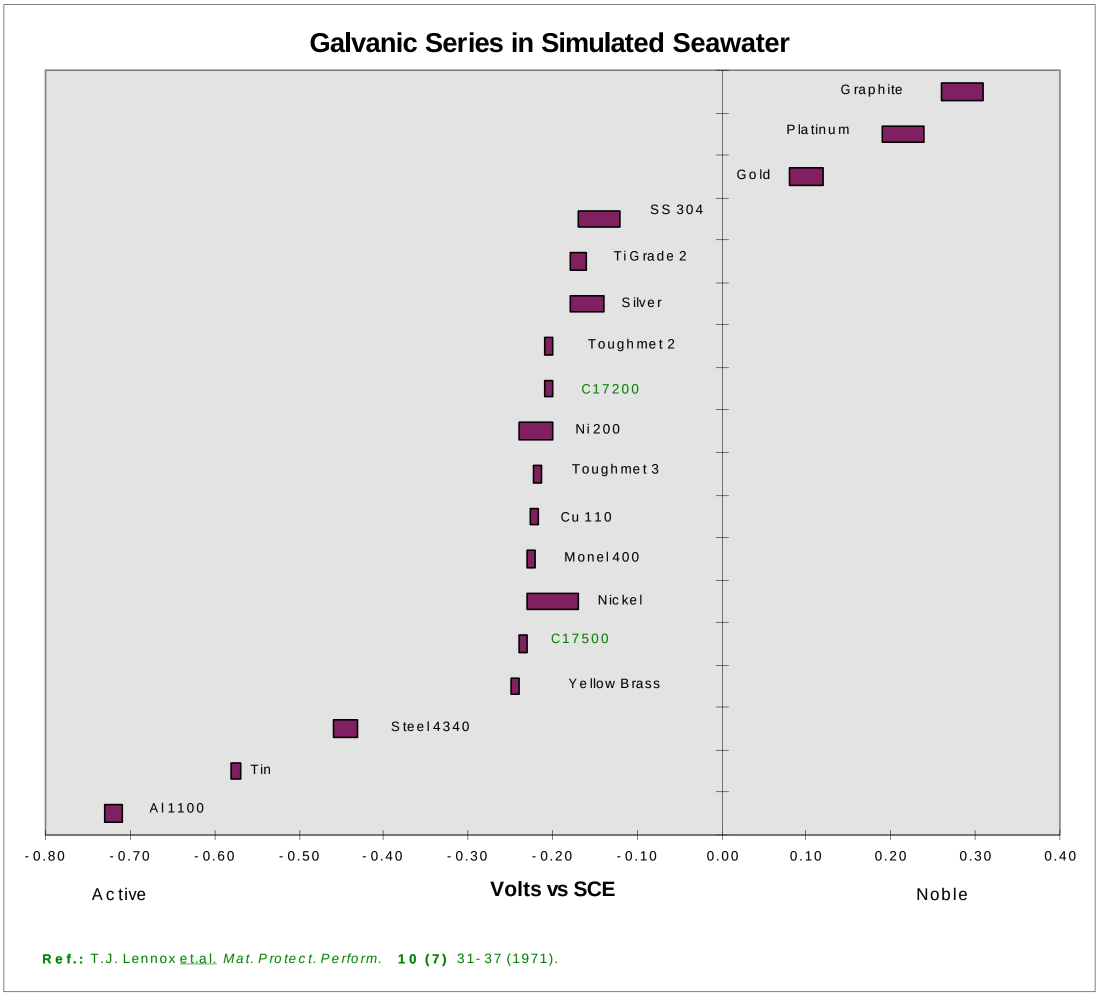
A method of commonly evaluating material susceptibility to Chloride SCC is ASTM Standard Practice G36, "Performing Stress-Corrosion Cracking in a Boiling Magnesium Chloride Solution." This accelerated test method incorporates C-ring specimens exposed to the solution for 1000 hrs or failure. The specimens were loaded to an applied stress of 100% of the yield strength. ToughMet® 3AT (C72900) experienced no failure in the these tests. *("Chloride Stress Corrosion," BWI-AT0024)*

Sulfide Stress Corrosion Cracking



ToughMet® 3CX110, ToughMet® 3AT90 and ToughMet® 3AT120 tested in NACE MRO 175 levels I, IV, and V environments according to TM0177. Subject tempers exhibited no cracking failures after thirty days exposure at 90 % of yield strength. ToughMet® also has extremely low general weight loss in sour environments.

Galvanic Series



A galvanic series is a tool for predicting which of two dissimilar metals (and/or alloys) will undergo an accelerated corrosion while in contact with the other in a conductive environment. The metal or alloy possessing the more negative (active or anodic) potential tends to suffer accelerated corrosion, while the metal or alloy possessing the more positive (noble or cathodic) potential tends to remain practically unaffected. *("A Guide To Galvanic Corrosion," BWI-AT0027)*

Appendix A

ToughMet® 3AT Datasheet

AT Temper — *ToughMet™ 3*

ToughMet™ is Brush Wellman's solution to your severe service material problems. By applying our EquaCast™ process, tailored alloying additions and spinodal hardening technology, we have engineered ToughMet™ to provide attributes beyond those typically found in a high-strength copper alloy.

- Exceptional resistance to corrosion and cavitation
- Outstanding lubricity and durability in demanding applications
- Highly uniform composition in all product forms
- Uniform microstructure in a variety of wrought shapes and sizes

ToughMet™ 3 in the wrought and spinodally hardened (AT) condition exhibits tensile strength up to 140 ksi and hardness up to HRC 34 in a Copper-15% Nickel-8%Tin alloy with excellent machinability.

Mechanical Properties

Temper	*Outside Diameter*	*Yield Strength 0.2% Offset (ksi)*	*Ultimate Tensile Strength (ksi)*	*Elongation (%)*	*Hardness (HRC)*
T3AT 120	< 4"	120	135	7	32
T3AT 120	≥ 4"	120	135	4	32
T3AT 110	< 4"	110	125	10	30
T3AT 110	≥ 4"	110	125	6	30
T3AT 90	< 4"	90	110	15	22
T3AT 90	≥ 4"	90	110	12	22

Typical minimum values. Consult your Brush Wellman representative to review your application requirements.

Physical Properties

Young's Modulus	18.5 x 10^6 psi
Poisson's Ratio	0.33
Electrical Conductivity	9% IACS
Thermal Conductivity	22 Btu/f/hr/°F
CTE (70 – 215 °F)	8.9 x 10^{-6}/°F
Density	0.323 lb/in^3
Fatigue Limit	60 ksi at R= -1*
Magnetic Permeability	< 1.001

*Fatigue at 10^6 cycles, 105ksi YS.

Availability

Our current capabilities are focused in rod and tube standard forms:

Rod: 1 - 8 inch diameter
Tube: 2 - 8 inch O.D.
Wall thickness > 15% of O.D.
Lengths to 20 feet

Rotary straightened mill finishes.
Tolerances per ASTM B249.

ToughMet® 3CX Datasheet

CX Temper

ToughMet™ 3

ToughMet™ is Brush Wellman's solution to your severe service material problems. By applying our EquaCast™ process, tailored alloying additions and spinodal hardening technology, we have engineered ToughMet™ to provide attributes beyond those typically found in a high-strength copper alloy.

- Exceptional resistance to corrosion and cavitation
- Outstanding lubricity and durability in demanding applications
- Highly uniform composition in all product forms
- Available in a wide range of continuous-cast shapes and sizes

ToughMet™ 3 in the cast and spinodally hardened (CX) condition exhibits tensile strength up to 120 ksi and hardness up to HRc 34 in a Copper - 15% Nickel - 8% Tin alloy with excellent machinability.

Mechanical Properties

Temper	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)	Hardness (HRc)
T3CX 105	105 (< 4" Ø)	110 (< 4" Ø)	4	30
T3CX 105	94.5 (≥ 4" Ø)	99 (≥ 4" Ø)	4	30
T3CX 90	90	105	6	27
T3CA 30	30	65	45	HRb 62

Typical minimum values. Consult your Brush Wellman representative to review your application requirements.

Physical Properties

Young's Modulus	18.5 x 10^6 psi
Poisson's Ratio	0.3
Electrical Conductivity	9% IACS
Thermal Conductivity	22 Btu/f/hr/°F
CTE (70 – 215 °F)	9.1 x 10^{-6}/°F
Density	0.323 lb/in^3
Magnetic Permeability	< 1.001

Some properties depend on strength level.

Availability

Brush Wellman provides a variety of cast and spinodally hardened forms:

Rods: 1 – 23 in. Ø
Hollow Bar: 2 - 17 in. O.D.
Specialty Shapes: Multi-hole and/or shapes with >1/2 in. wall

Tolerances in accordance with ASTM B505.

AD0012/0802

Appendix B

Stock Status on January 04

in inch

ToughMet™ 3 Stock Sizes		
CX105* Rod	CX105* Tube	AT110** Rod
Diameter	OD x ID	Diameter
1¹/₈"	2" x 1"	1"
1½"	2½" x 1½"	1½"
2"	3" x 1¾"	1¾"
2½"	3½" x 2½"	2"
3"	4" x 2"	2½"
3½"	4¼" x 2"	2.8"
4"	5" x 4"	3"
5"	5½" x 3"	3¼"
	6¼" x 3½"	3½"
	7" x 2"	3¾"
	7¹/₈" x 4"	4"
	8" x 5"	5"
	10" x 7"	
	11¼" x 2½"	

in mm

ToughMet™ 3 Stock Sizes		
CX105* Rod	CX105 Tube	AT110** Rod
Diameter	OD x ID	Diameter
28.575	50.8 x 25.4	25.4
38.1	63.5 x 38.1	38.1
50.8	76.2 x 44.45	44.45
63.5	88.9 x 63.5	50.8
76.2	101.6 x 50.8	63.5
88.9	107.95 x 50.8	71.12
101.6	127 x 101.6	76.2
127	139.7 x 76.2	82.55
	158.75 x 88.9	88.9
	177.8 x 50.8	95.25
	180.975 x 101.6	101.6
	203.2 x 127	127
	254 x 177.8	
	285.75 x 63.5	

Size limit at casting stage is 24” (610 mm)
Available material in plate form is presently limited to 21” (533 mm) max.
5” (127 mm) thick plate in stock has dimensions 18” x 50” x 5” (457 x 1270 mm)
Biggest tube in stock has OD 15” (381 mm)

CX105* as cast and spinodal hardened
Min. yield strength 715 N/mm2; Min. tensile strength 750 N/mm2; HRC30

AT110** solution annealed and spinodal hardened
Min. yield strength 750 N/mm2; Min. tensile strength 850 N/mm2; HRC31