MATERION

TECH BRIEF

DESIGNING AND WORKING WITH HEAVILY LOADED BUSHINGS MADE FROM TOUGHMET® ALLOY

Materion Performance Alloys and Composites produces a series of alloys under the name ToughMet alloys. These spinodally hardened copper nickel tin alloys have proven success in thrust bearings, journal/plain/sleeve bearings, and linear sliding bearings. Following are a series of recommendations to allow you to get the most out or your bushing/bearing design.

PART 1: DESIGNING WITH TOUGHMET ALLOY

As a 'drop-in' replacement for other bronze or steel plain bushings, ToughMet bushings can have a longer lifespan, withstand higher loads, and employ a wider range of lubrication options.

This Tech Brief describes how to design, how to machine and run ToughMet grease lubricated journal bushings, while highlighting material specific requirements such as permissible loads, mating material hardness, interference fit, clearances and machining considerations.

ToughMet bushings can be designed in a manner very similar to bronze bushings. Interference fit (in a housing) and clearance for the pin can be calculated the same as those for standard bronze bushings. ToughMet Bushing Tolerancing Calculations can be found in Appendix C. Please note: Bushing designs often evolve over time to accommodate material inadequacies. With ToughMet, consider the original spirit of the design.

CONTINUOUS MAXIMUM LOAD

Using ToughMet alloy as a replacement for standard bronze bushings, it is possible to apply a higher load over an equivalent area or reduce the contact area under the existing load. The maximum dynamic load in cases of limited motion, as determined by the galling threshold, ranges 70 – 100 ksi for most steels coupled with ToughMet alloys. The maximum static load ToughMet alloy can withstand, as determined by its compressive strength, is 110 ksi. PV limit testing of ToughMet alloy indicates that ToughMet material can be used at values in excess of 375,000 psi sfm.

MATING MATERIALS AND SURFACES

To ensure preferential wear on the ToughMet bushing and minimize wear on both materials, choose a mating surface material with minimum hardness of 40 HRC. Materion recommends a hardness of 60 HRC or higher. This will ensure the steel remains smooth and does not cause excessive wear on the ToughMet alloy. These materials include hardened carbon steel, precipitation hardened stainless steels, chrome plated steels, etc. The optimum surface finish for the mating material is below 10 μ inches running against ToughMet alloy with surface roughness below 16 μ inches. For heavily loaded, slower moving joints, a mating surface roughness of 32 μ inches against a ToughMet alloy surface roughness of 64 μ inches is acceptable. In any case, the mating surface should be smoother than the ToughMet alloy. The harder, smoother mating surface will wear-in the ToughMet material, polishing and work hardening it. The near-surface hardness of ToughMet alloy after work hardening is typically 36 HRC. See section on Wear-in for further information.

PLANNING INTERFERENCE FIT

ToughMet alloy is often inserted into the housing via press fit or shrink fit methods. For a press-fit, a housing surface roughness of approximately 32 μ inches against the ToughMet alloy surface may assist in the method. It is acceptable to use liquid nitrogen or refrigeration, for example, at -40° F for a shrink fit. ToughMet alloy has a lower elastic modulus than that of steel, which reduces the holding force of the interference fit. To correct for the difference when substituting ToughMet alloy for steel, increase the interference fit by 50%. For optimal performance, Materion recommends boring after installation to obtain needed cylindricity and clearance tolerance. This is especially important when two or more bushings reside on the same pin, to limit the effect of 'stacking' tolerances.

The recommended minimum interference fit is 0.04% (i.e. the diameter of the bushing OD should be 0.4% larger than the diameter of the housing bore). The upper limit for interference can be as high as 0.4% for ToughMet alloy. However, such a large interference may not be feasible with a shrink fit (with a CTE of 9.6 x 10^{-6} per degree F, a dry ice/alcohol bath will shrink T3 ~0.09% and liquid nitrogen will shrink T3 0.3%). It should be determined if the housing can withstand the stress created by higher levels of interference. Per ANSI class FN2 guidelines, cast iron housings should not be used in fits with an interference exceeding 0.28%. The ANSI Class FN2 force fit as well as the ISO H7/s6 fit per ISO 286-2 are acceptable fits for ToughMet bushings in steel housings.

If ToughMet material is press fit into a housing, the approximate force needed at full insertion is given by

$$F(tons) \approx 65 \times Interference(\%) \times Wall_{Thickness}(in.) \times Length(in.)$$

This calculation assumes a thick-walled, steel housing and a friction coefficient of 0.1. A thinner housing or lower modulus housing will require less force. This insertion force may limit the maximum interference.

For smaller sizes, the machining tolerance will dictate the maximum interference.

BUSHING BORE SHRINKAGE FROM INTERFERENCE:

During a shrink or force fit of a ToughMet bushing into a housing with an interfering fit, the inner diameter (ID) of the bushing is reduced. In the case of a thin-walled ToughMet bushing in a thick-walled steel housing, the ID of the bushing will shrink 85% of the diametrical interference. When ToughMet alloy is placed in a housing of lower modulus, or thinner wall, the amount of shrink will be substantially smaller. Approximate factors for this are given in Appendix C: Table 1. In the case of a cylindrical bushing fit in a cylindrical housing, a good estimate of the ID shrinkage can be made with an application of the Lamé equation.[2] Actual shrinkage will be greater at the center than at the edges, due to edge effects for which the Lamé equation does not account. Also, if the bore is not centered in the housing, the resultant forces on the bushing from interference may result in a bushing ID that is out of round. The actual shrink would need to be modeled by FEA methods. In-line boring is recommended.

CLEARANCE

The running clearance between a ToughMet bushing and a mating pin is system specific. A good starting point is the H7/f6 non-ferrous standard fit from ISO 286-2. Be sure to include shrinkage in the bushing ID due to interference fits (see previous section). Like other bronzes, ToughMet alloy has a higher coefficient of thermal expansion compared to that of steel. Care should be taken to prevent loss of clearance in higher temperature applications or those with a wide temperature range as the two mating materials may expand at differing rates. Typically a steel pin will be used, so the clearance may increase at elevated temperature if the bushing is free to expand. However, the ID of a ToughMet bushing confined in a steel housing may decrease at elevated temperature due to thermal expansion and result in the loss of clearance.

LUBRICATION GROOVES

Because ToughMet alloy works well in boundary lubricated situations, fewer grooves can be used maximizing the bearing surface and reducing contact pressure. In some cases, grooves can be eliminated altogether. Grooves are best placed with some portion of the length perpendicular to the direction of motion.[1] Lubrication can be fed through either the 'pin' or the bushing. The Cast Bronze Bearing Design Manual[3] is a good resource for further information on groove design.

PART 2: WORKING WITH TOUGHMET ALLOY

TOUGHMET STOCK FINISHING ALLOWANCES

Each form and temper of ToughMet has different finishing allowances. Please refer to Appendix A to find correct ordering size. A Materion customer service representative can help determine appropriate dimensions.

MACHINING RECOMMENDATIONS

ToughMet alloy is typically a short chip copper alloy and machines very well, especially when aided with chip breakers. ToughMet should be machined in the "as-received" condition, with a harder grade of carbide to minimize wear. Grade C5 is recommended for most applications. Chip breakers incorporated into the insert aid in producing a very short, manageable chip. Surface finishes finer than 100 micro inches (2.5 microns) Ra are possible with feeds as large as 0.004 inch (0.1 mm) per revolution. Liquid coolant is recommended. Positive rake angles are strongly recommended.

Milling is best performed with a carbide-inserted milling cutter. The same cutters used for P20 tool steels can be employed; however, a positive rake angle is advantageous.

Appendix B suggests recommended machining parameters for ToughMet. These parameters are conservative values based on simple machining studies. Variations of these may be necessary depending on part geometry and available machine tools. For machining of thin-walled bushings, the minimum achievable tolerance by conventional machining practices is given by:

$$tolerance = \frac{length}{wall_{Thickness}} \times 0.0001in.$$

To achieve a smaller tolerance, additional processes such as grinding or honing, should be considered. Care must be taken to understand the effect of the fixturing (e.g. three jaw chuck, arbor, etc.) on the free state dimensions of the bushing. Aggressive material removal, especially on open contour designs can impart machining stresses into the material, causing 'movement' when removed from the machining constraints. Using 'diminishing' cuts and sharp tools may help alleviate this situation. Please consult with the Materion Customer Technical Service Department.

Machining burrs can be detrimental to ToughMet alloy's performance in tighter tolerance situations. Special features, such as chamfers or a radius, should be cut in a direction opposite to the bushing surface, so any burrs would be located at the end (and away from the contact surface.)

SCRAP

Chips can also be mixed and sold with other copper alloy scrap. Materion offers a premium for clean, segregated ToughMet alloy scrap. Call +1-419-862-4233 or your local agent for details.

PART 3: RUNNING WITH TOUGHMET ALLOY

BUSHING OPERATING LUBRICANTS

ToughMet alloy is compatible with most oils and greases. There is no need for a special lubricant. ToughMet alloy has also been run with water, salt water, graphite and mild soap solutions as lubricant.

WEAR-IN

Under heavily loaded conditions, there is a very brief initial period where the ToughMet alloy surface work hardens, increasing by about 6 HRC pts. There may be a small material transfer of ToughMet alloy to the mating surface. This transfer does not measurably affect the diameter of the pin or the clearance between the two surfaces, nor is it any indication of failure. This transfer is a one-time process, and period of time depends upon speeds and pressures in the system. If the system is disassembled, and the material transfer cleaned, wear-in will happen again when reassembled. (Actual system wear can be tested as any other bronze: change in wall thickness, increase in clearances or observation of copper contaminated lubricant.)

FURTHER INFORMATION

For additional literature, further information, or technical assistance on alloy properties or processing of ToughMet alloys, contact Materion's Customer Technical Services Group at 1 216.383.6800.

REFERENCES:

1. Henrik Strand, "Design, Testing and Analysis of Journal Bearings for Construction Equipment. (Doctoral Thesis, KTH, 2005), 36. http://kth.divaportal.org/smash/record.jsf?pid=diva2:11656

2. Timoshenko and Goodier, Theory of Elasticity. 1970, McGraw-Hill, New York, NY, p.70.

3. Ripple, Harry. C. Cast Bronze Bearing Design Manual. 1993 Copper Development Association Inc, New York, NY

APPENDIX A: ORDERING STOCK TOUGHMET ALLOY

TABLE #1: ALLOWANCES FOR ORDERING TOUGHMET CX ROD/TUBE

Finished Size	Add to Outside Diameter for 'Order Size'
Up to and Including 9" (229 mm) OD	0.125" (3.2 mm)
Over 9" (229 mm) OD	0.225" (5.7 mm)

TABLE #2: OUTSIDE DIAMETER ALLOWANCES FOR ORDERING AT/TS ROD AND TUBE

Finished Size	Add to Outside Diameter for 'Order Size'
Up to and Including 7" (178 mm) OD	0.060" (1.5 mm)
Over 7" (178 mm) OD	0.125" (3.2 mm)

APPENDIX B: MACHINING TOUGHMET ALLOY

TURNING

Alloy	Tool Material	Surface Speed†		Roughing Feed at Depth		Finishing Feed	
		(sfm)	(m/min)	(mil/rev)	(mm/rev)	(mil/rev)	(mm/rev)
ToughMet 2 CX	HSS C2 (K20) Carbide	200 – 500 300 – 3000	60 – 150 90 – 900	6 – 10 @ 0.050" 6 – 20 @ 0.100"	0.15 – 0.25 @ 1.3 mm 0.15 – 0.5 @ 2.5 mm	2 – 5 @ 0.025" 2 – 5 @ 0.030"	0.05 – 0.15 @ 0.6 mm 0.05 – 0.15 @ 0.75 mm
ToughMet 3 CX	HSS C5 (P40) Carbide	50 400 - 800	15 120 - 240	1 – 2 @ 0.050" 5 – 12 @ 0.100"	0.025 – 0.05 @ 1.3 mm 0.13 – 0.3 @ 2.5 mm	1 – 2 @ 0.010" 2 – 4 @ 0.010"	0.025 – 0.05 @ 0.25 mm 0.05 – 0.1 @ 0.25 mm
ToughMet 3 AT	HSS C5 (P40) Carbide	50 400-800	15 120 – 240	1 – 2 @ 0.050" 5 – 12 @ 0.100"	0.025 – 0.05 @ 1.3 mm 0.13 – 0.3 @ 2.5 mm	1 – 2 @ 0.010" 2 – 4 @ 0.010"	0.025 – 0.05 @ 0.25 mm 0.05 – 0.1 @ 0.25 mm

† The speeds presented are for ToughMet 2 CX 90, ToughMet 3 CX 110, and ToughMet 3 AT 110 tempers. The speeds for softer tempers can be increased in proportion to the reduction of yield strength. It is recommended to hold feeds to the same value.

Note: Mil measurements refer to one thousandth of an inch.

MILLING

Alloy	Tool Material	Surface Speed †		Roughing Feed		Finishing Feed	
		(sfm)	(m/min)	(mil/tooth)	(mm/tooth)	(mil/tooth)	(mm/tooth)
ToughMet 2 CX	HSS C2 (K20) Carbide	200 – 500 300 – 3000	60 – 150 90 – 900	3 – 5 @ 0.050" 6 – 20 @ 0.100"	0.075 – 0.13 @ 0.05 mm 0.15 – 0.5 @ 2.5 mm	2 – 5 @ 0.010" 2 – 5 @ 0.025"	0.05 – 0.13 @ 0.25 mm 0.05 – 0.13 @ 0.65 mm
ToughMet 3 CX	HSS C5 (P40) Carbide	100 300 - 500	30 90 - 250	1 – 3 @ 0.050" 5 – 15 @ 0.125"	0.025 – 0.075 @ 1.3 mm 0.13 – 0.4 @ 3 mm	1 – 2 @ 0.015" 2 – 4 @ 0.010"	0.025 – 0.05 @ 0.4 mm 0.05 – 0.1 @ 0.25 mm
ToughMet 3 AT	HSS C5 (P40) Carbide	100 300-500	30 90 – 150	1 – 3 @ 0.050" 5 – 15 @ 0.125"	0.025 – 0.075 @ 1.3 mm 0.13 – 0.4 @ 3 mm	1 – 2 @ 0.015" 2 – 4 @ 0.010"	0.025 – 0.05 @ 0.4 mm 0.05 – 0.1 @ 0.25 mm

DRILLING AND TAPPING

Alloy	Tool Material	Surface Speed†		Feed		Tapping Speed	
		(sfm)	(m/min)	(mil/rev)	(mm/rev)	(sfm)	(m/min)
ToughMet 2 CX	HSS C2 (K20) Carbide	100 – 300 300 – 3000	30 – 90 90 – 900	10 - 20 6 – 20	0.25 – 0.5 0.15 – 0.5	15 15	4.5 4.5
ToughMet 3 CX	Cobalt Steel C5 (P40) Carbide	50 150 - 500	15 45 - 150	2 – 10 5 – 20	0.05 – 0.25 0.13 – 0.5	10 10	3 3
ToughMet 3 AT	Cobalt Steel C5 (P40) Carbide	50 150-500	15 45 – 150	2 – 10 5 – 20	0.05 – 0.25 0.13 – 0.5	10 10	3 3

GRINDING

SAWING

Alloy	Grinding Wheel Type	Wheel Speed		Saw Blade		Blade Type	Blade Speed	
		(sfm)	(m/min)	(tpi)	(mm/tooth)	(mm/tooth)	(fpm)	(m/min)
ToughMet 2 CX	A54LV	5500 – 6500	1700 – 2000	1.2 / 1.8	18 – 12.5	Variable Pitch Carbide Tipped Blade	80	25
ToughMet 3 CX	A54LV	5500 – 6500	1700 – 2000	1.2 / 1.8	18 – 12.5	Variable Pitch Carbide Tipped Blade	80	25
ToughMet 3 AT	A54LV	5500 – 6500	1700 – 2000	1.2 / 1.8	18 – 12.5	Variable Pitch Carbide Tipped Blade	80	25

† The speeds presented are for ToughMet 2 CX 90, ToughMet 3 CX 110, and ToughMet 3 AT 110 tempers. The speeds for softer tempers can be increased in proportion to the reduction of yield strength. It is recommended to hold feeds to the same value.

Note: Mil measurements refer to one thousandth of an inch.

APPENDIX C: TOUGHMET TOLERANCING WORKSHEET

TOUGHMET® BUSHING TOLERANCING WORKSHEET		
1. Nominal bore diameter:	L1	
Enter design dimension.		
2. Minimum interference of housing and bushing:	L2	
		= 0.0004 x L1
3. Tolerance of interference fit (sum of ISO 286-2 IT Grades 6 & 7):	L3	
Enter sum of tolerance for 6 and 7 band from ISO or ANSI table or use formula provided. Proper units (inches) must be used in formula.		$= 0.0013'' \times [L1\ (in.)]^{0.35}$
4. Minimum housing bore:	L4	
		= L1
5. Maximum housing bore:	L5	
Tolerance on bore is 60% of total tolerance.		= L4 + 0.6 x L3
6. Minimum bushing OD:	L6	
		= L5 + L2
7. Maximum bushing OD:	L7	
Tolerance on the OD is 40% of the total tolerance.		= L6 + 0.4 x L3
8. Nominal shaft OD:	L8	
Enter design dimension.		
9. Minimum running clearance (ISO 286-2 Shaft Limit Deviation f):	L9	
Enter sum of fit limit "f" from ISO or ANSI table or use formula provided. Proper units (inches) must be used in formula.		$= 0.00074'' \times [L8\ (in.)]^{0.43}$
10. Bushing ID shrinkage factor due to interference:	L10	
		Enter factor from Table 1 below
11. Maximum bushing ID shrinkage due to interference:	L11	
		= L10 x (L2 + L3)
12. Total tolerance for clearance (sum of ISO 286-2 IT Grades 7 & 8):	L12	
Enter sum of tolerance for 7 and 8 band from ISO or ANSI table or use formula provided. Proper units (inches) must be used in formula.		$= 0.002'' \times [L8\ (in.)]^{0.36}$
13. Variation in interference fit transmitted to the bushing ID:	L13	
		= L10 x L3
14. Tolerance available to machining:	L14	
If calculated value is less than 0.002'', set to 0.002''.		= L12 - L13
15. Minimum bushing ID:	L15	
		= L8 + L11
16. Maximum bushing ID:	L16	
If tolerance (L16 - L15) on bushing ID is too tight, increase the value on line 14 and recalculate lines 15 through 18.		= L15 + 0.6 x L14
17. Maximum shaft OD:	L17	
		= L8 - L9
18. Minimum shaft OD:	L18	
If tolerance (L16 - L15) on bushing ID is too tight, increase the value on line 14 and recalculate lines 15 through 18.		= L17 - 0.4 x L14

TABLE 1: FRACTION OF INTERFERENCE TRANSMITTED TO ID OF BUSHING

Condition	L10
ID bored or machined to size after installation	0
Thin-walled bushing (< 10% of bushing OD) in heavy-walled (> 50% of bushing OD) steel housing	0.85
Bushing wall ≈ housing wall (steel only)	0.6
Thin-walled bushing in a heavy-walled aluminum housing	0.7
Thick-walled bushing (> 30% of bushing OD) in heavy-walled (> 50% of bushing OD) steel housing	0.5

This table represents general values. For more precise values, choose the appropriate contour value from the charts below.