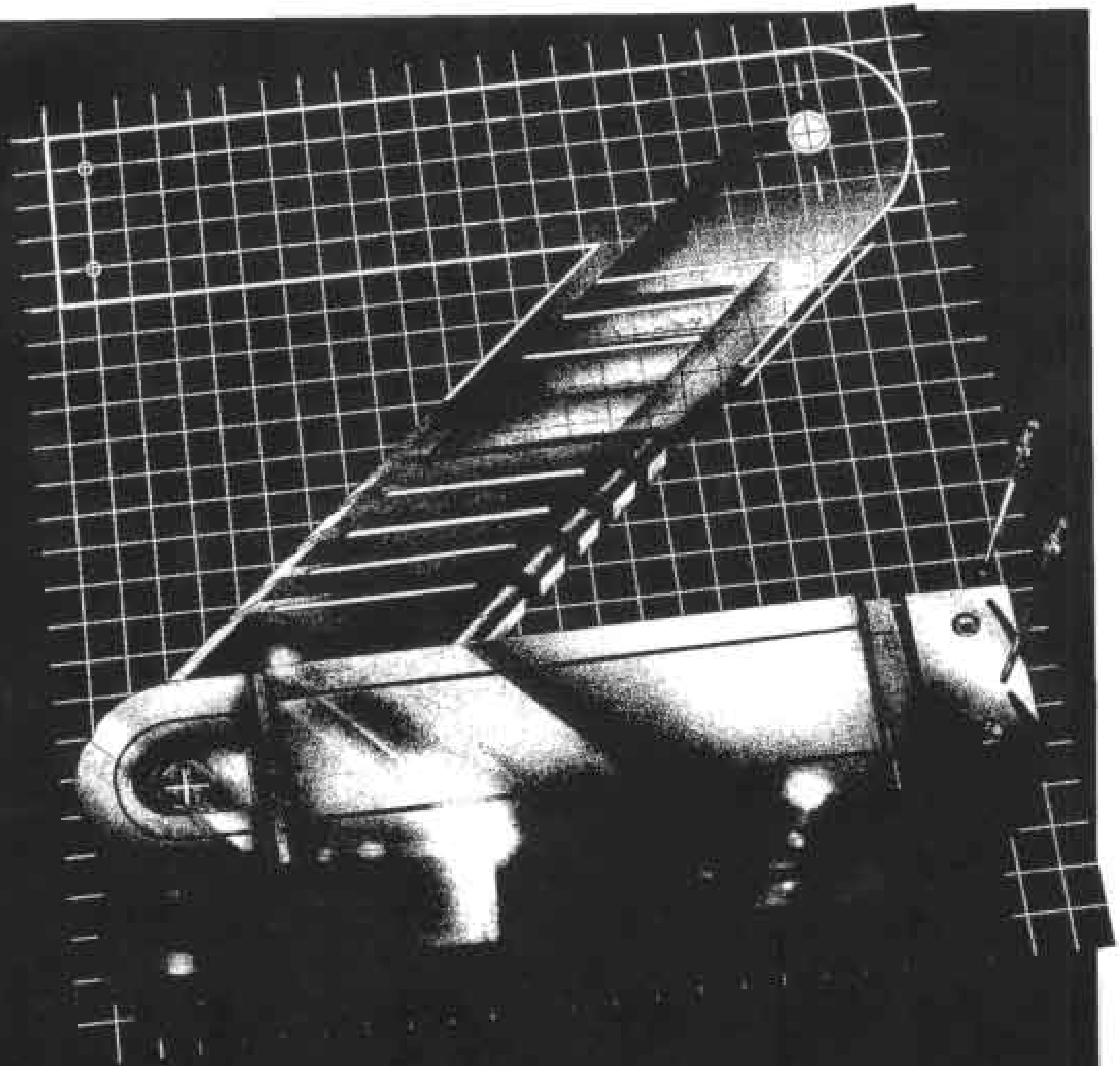
BEARING DESIGN MANUAL



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ZINC ALUMINUM ALLOY DESIGN MANUAL FOR CONTINUOUS ROTATION BEARINGS

by
R.J. BARNHURST

January 1988

Noranda Research Centre
240 Hymus Boulevard
Pointe Claire
Québec, Canada
H9R 1G5

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FOREWORD

This document is the net result of over five years of joint research by Noranda Research Centre, Quebec, Canada, the Industrial Materials Research Institute, Quebec, Canada and the Amax Materials Research Laboratories, Michigan, U.S.A. Funding was provided by Canadian Electrolytic Zinc Ltd., Quebec, Canada, National Research Council of Canada, and Amax Base Metals Division, Amax Inc., N.Y., U.S.A. Additional funding from the International Lead Zinc Research Organization (ILZRO) Inc., N.C., U.S.A. provided for the development of the mechanical properties of the continuously cast ZA alloys.

Many avenues of research into ZA bearings remain to be explored and it is the present and future requirements of those who use this manual to design ZA bearings, together with the results of field applications, which will determine the direction of further study. Indeed the original design of the experimental work conducted over the last five years was based, in part, upon consultation with, and recommendations from, the bearing industry.

It is the raison d'être of this manual to assist and promote the use of zinc alloys in journal bearing design. It is hoped that the bearing user and designer will find herein the means to superior bearing performance made possible by ZA alloys.

R.J. Barnhurst
Noranda Research Centre
January 1988

1 INTRODUCTION

The ZA family of alloys, namely ZA-8, ZA-12 and ZA-27 were developed as general foundry alloys during the 1960's and 1970's. The ZA-8 and ZA-27 alloys were developed by Noranda Research Centre during the 1970's while ZA-12 was developed by the New Jersey Zinc Co. Ltd. in the 1960's, under funding from the International Lead Zinc Research Organization (ILZRO), North Carolina.

During the period 1981-1986, the bearing properties of ZA alloys were investigated by Noranda Research Centre (under funding from the Canadian Electrolytic Zinc Co., Valleyfield, Québec) and the Industrial Materials Research Institute (National Research Council) Boucherville, Québec. It was concluded from the study of full size bearings that ZA-12 and ZA-27 had equivalent or superior bearing performance to

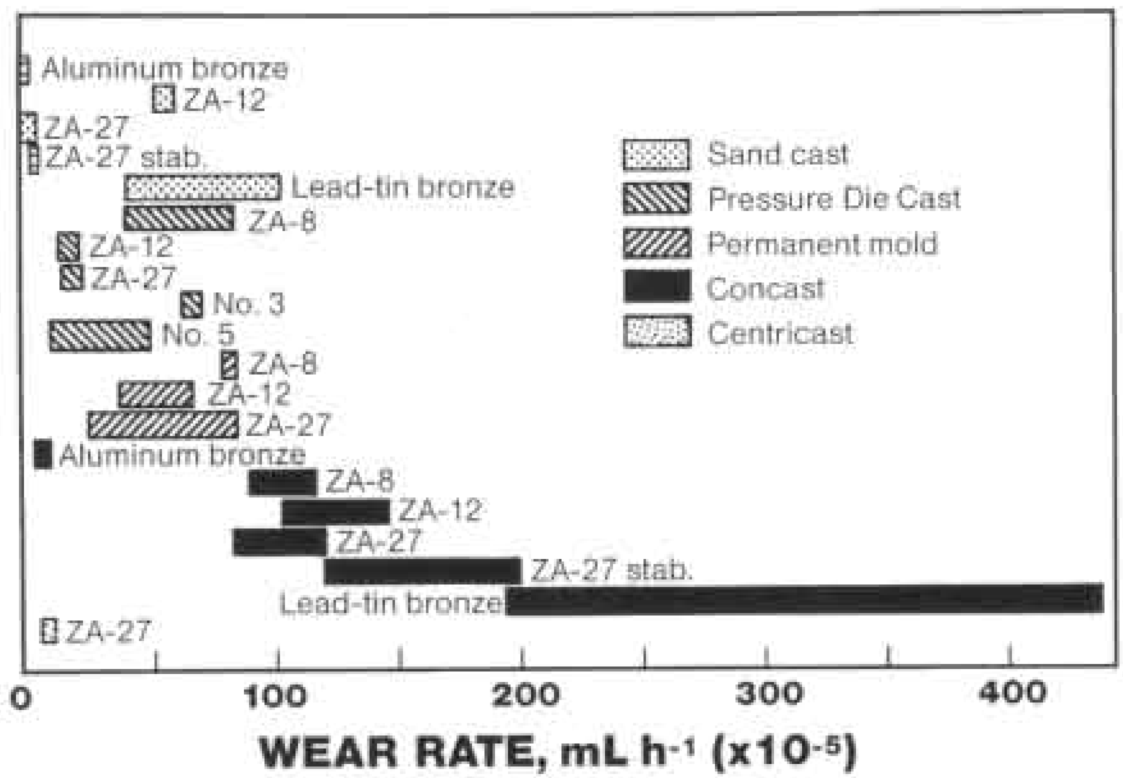


Figure 1 – Comparative wear rate of zinc and bronze alloys produced by several different processes. The wear resistance of die cast and permanent moulded ZA alloys falls between that for sand cast and concast alloys [1,2]. Stabilized alloys are heat treated for 12 h at 250°C (482°F) and furnace cooled.

bronze alloys, particularly C93200 (SAE 660) lead — tin bronze. In addition, a Block on Ring test procedure was used to identify the relative wear behaviour of ZA alloys in up to 5 metallurgical conditions, together with a number of comparative materials. Here, it was found that sand cast ZA-27 had the best overall performance in terms of wear rate to all other forms of zinc alloys. Full listing of the findings can be found in Figure 1. The relative wear behaviour of pressure die cast, permanent mould (gravity die) cast and centrifugally cast ZA and zinc die casting alloys can be assessed approximately, based on the performance of sand cast and concast ZA bearings given herein.

The objective of this manual is to provide design data for ZA alloys for bearing applications. In this regard the manual can be used hand in hand with the bearing design manual for bronze alloys issued by the Cast Bronze Bearing Institute. Where significant differences in behaviour exist between ZA and bronze bearings, these are clearly pointed out in terms of design changes required to accommodate ZA alloys. As new work is completed on various aspects of ZA bearing performance, these will be incorporated as an addendum or new edition to the manual.

This manual is devoted to the design of individually cast or machined journal bearings, however, these data can also be employed where the bearing becomes an integral part of the overall functional casting design. The flexibility of ZA alloys allowing casting to near net shape with close tolerances can thereby eliminate the need for traditional bearing inserts.

2 SPECIFICATIONS AND GENERAL METALLURGY

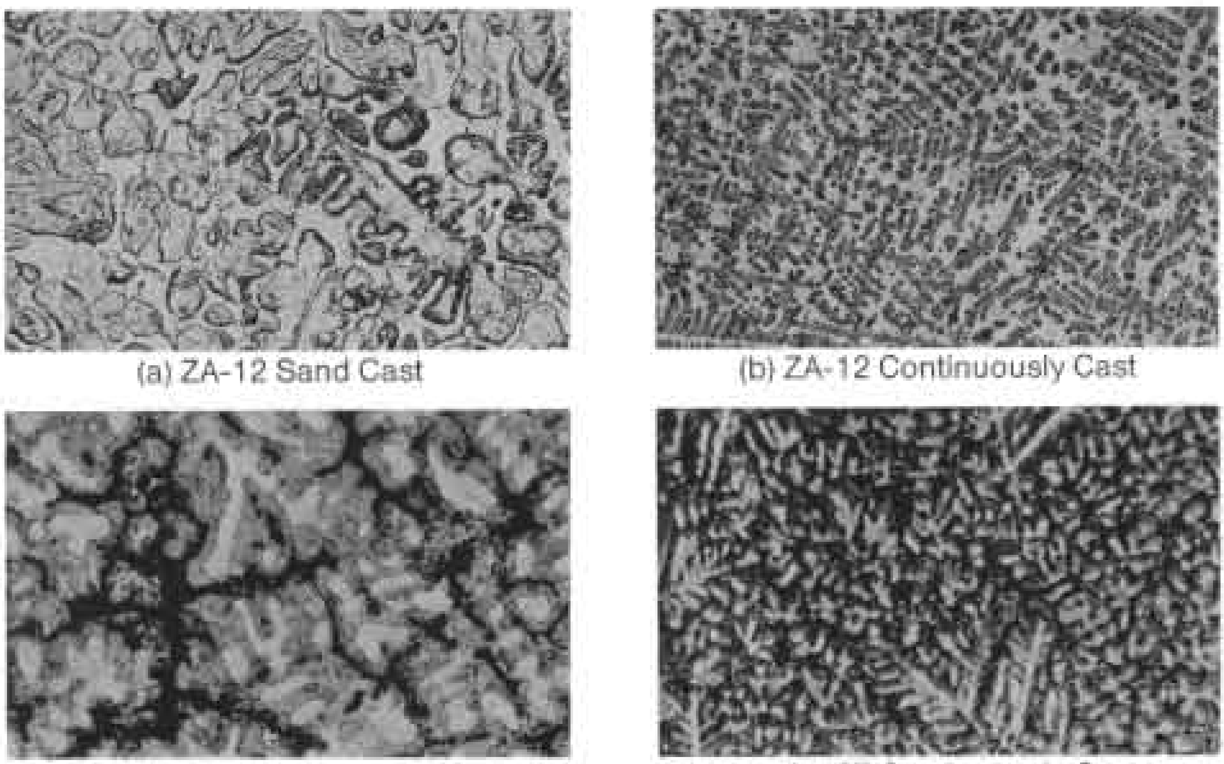
The ZA-12 and ZA-27 alloys are two members of the ZA family that are regularly used in bearing applications. The chemical specification for ZA-12 and ZA-27 ingot is shown in Table 1 and which follows the present ASTM specification B669-84, "Zinc Alloys in Ingot Form for Foundry Casting". The ZA-12 alloy contains approximately 11% aluminum and 1% copper combined with a small amount of magnesium (0.02%). The ZA-27 alloy contains, on average, 27% aluminum with 2 — 2.5% copper and magnesium in the range of 0.01 — 0.02%. The microstructure of the alloys are dendritic/eutectic typical of many wide freezing range alloys, i.e. primary aluminum rich dendrites (α for ZA-27 or β for ZA-12), surrounded by a eutectic of varying amount, consisting of $\alpha + \eta$ phases. Copper rich ϵ ($CuZn_4$) particles are present in the interdendritic liquid. Photomicrographs of the two alloys in the continuously cast and sand cast conditions are shown in Figure 2. In general, the more rapid the solidification the finer the microstructure and dispersion of precipitates. It is for these reasons that ZA alloys produced by various processes show differences in bearing and mechanical property behaviour. The mechanical and

TABLE 1

Compositional Ranges in wt% of ZA-12 and ZA-27 Casting Alloys as per ASTM B669-84 Ingot Specification

Element	ZA-12	ZA-27
Aluminum	10.5 – 11.5	25.0 – 28.0
Copper	0.5 – 1.25	2.0 – 2.5
Magnesium	0.015 – 0.03	0.01 – 0.02

Impurity limits: Pb – 0.004, Cd – 0.003, Sn – 0.002, Fe – 0.075 for ZA-12, 0.10 for ZA-27



(a) ZA-12 Sand Cast

(b) ZA-12 Continuously Cast

(c) ZA-27 Sand Cast

(d) ZA-27 Continuously Cast

Figure 2 – Microstructure of ZA-12 and ZA-27 in the sand cast and continuously cast conditions. The relative amounts of dendritic and eutectic phases in the centrifugally cast bearings varies with casting conditions. (magnification × 125)

physical properties of sand and continuously cast ZA-12 and ZA-27 at 20 and 100°C (68 and 212°F) are given in Table 2([3]). The mechanical properties of ZA alloys are readily assessed by reference to the table. Both the tensile strength and hardness are decreased at 100°C (212°F) whereas ductility and impact strength are markedly increased. An important design property at normal bearing operating stresses is creep strength. Bearing stresses up to 6.9 MPa (1,000 lb in^{-2}) are recommended for ZA alloys operating under boundary or mixed lubrication conditions where low wear rate is required. At this stress level a steady state creep rate of less than 1% in 100,000 h (11.4 years) is realized at temperatures not exceeding 120°C (248°F).

In this manual, discussion is devoted exclusively to continuous rotation bearings and assumes a working knowledge of the design of bronze bearings.

Table 2

Physical Properties

PROPERTY	UNIT	ZA-12	ZA-27
Specific Gravity		6.03	5
Density	kg m^{-3} (lb ft^{-3})	6030 (376)	5000 (312)
Melting Range	°C (°F)	377-432 (710-810)	375-484 (708-903)
Coefficient of Linear Expansion 20-100°C (68°F-212°F)	K^{-1} (°F^{-1})	24 x 10^{-6} (13.4 x 10^{-6})	26 x 10^{-6} (14.4 x 10^{-6})
Electrical Conductivity at 20°C (68°F)	$\mu\Omega$ cm ($\mu\Omega$ in.)	6.1 (2.4)	5.8 (2.3)
Electrical Conductivity at 24°C (68°F)	%IACS	28.3	29.7
Thermal Conductivity at 24°C (75°F)	W m^{-1} K^{-1} (BTU in.$^{-1}$ h^{-1} ft^{-2} °F^{-1})	116 (805)	125.5 (870)
Specific Heat 24-92°C (75-198°F)	J kg K^{-1} (BTU lb^{-1} °F^{-1})	450 (0.107)	525 (0.125)
Latent Heat of Fusion 380-415°C (716-779°F)	kJ kg^{-1} (BTU lb^{-1})	118 (51)	128 (55)
Solid Contraction [8]	(%)	≈1 to 1.3	≈1.3

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TABLE 2

Mechanical Properties

ALLOY		SAND CAST			
		ZA-12			
PROPERTY	UNIT	As Cast	As Cast	As Cast	As Cast & Stabilized[1]
		20°C (68°F)	100°C (212°F)	20°C (68°F)	20°C (68°F)
Tensile Strength	MPa (lb in^{-2})	275-317 (40000-46000)	226-230 32780-33360)	400-441 (58000-64000)	290-324 (42000-47000)
Yield Strength 0.2% Offset	MPa (lb in^{-2})	207-214 (30000-31000)		365-372 (53000-54000)	234-241 (34000-35000)
Elongation, % in 5.08 cm (2.0 in.)		1-2	30-36	3-6	2-4
Young's Modulus	MPa (lb in^{-2})	82.1 x 10^3 (11.9 x 10^6)		77.9 x 10^3 (11.3 x 10^6)	85 x 10^3 (12.3 x 10^6)
Hardness Brinell 500-10-30s		92-96	68-72	110-120	85-95
Hardness Vickers 5 kg		115-116		135-140	105
Fatique Endurance Limit (Rotary Bending)	MPa (lb in^{-2})	≈103 (≈15000)		≈172 (≈25000)	
Shear Strength	MPa (lb in^{-2})	248-262 (36000-38000)		283-297 (41000-43000)	
Compressive Yield Strength, 0.1% Offset	MPa (lb in^{-2})	224-234 (32500-34000)		328-332 (47500-48200)	
Creep Strength[2]	MPa (lb in^{-2})	>70 (>10,000)	≈9 (≈1300)	>70 (>10000)	>90 (>13,000)
Creep Rate	%/1000h	0.2[3]	0.16[4]	≈0.08[5]	≈0.38[3]
Impact Strength[6] at 20°C (68°F)	J (ft lb)	23-30 (17-22)	76-92 (56-68)	34-54 (25-40)	27-38 (20-28)
Poisson's Ratio		0.32-0.33		0.30-0.31	

Nomenclature: 1. Heat treated for 12h at 250°C (482°F), followed by furnace cooling.
2. Stress to produce a steady state creep rate of 1% in 100000h (11.4y).
3. Creep rate at a stress of 138 MPa (20000 lb in.$^{-2}$)

TABLE 2

	ZA-27		CONTINUOUSLY CAST ZA-12		CONTINUOUSLY CAST ZA-27		
	As Cast	As Cast & Stabilized(1)	As Cast	As Cast	As Cast	As Cast	As Cast & Stabilized(1)
	100°C (212°F)	100°C (212°F)	20°C (68°F)	100°C (212°F)	20°C (68°F)	100°C (212°F)	100°C (212°F)
	280-286 (40610-41480)	197-203 (28570-29440)	408-430 (59200-62400)	203-213 (29480-30980)	444-484 (64000-70000)	275-283 (40830-41030)	226-230 (32780-33360)
			303-323 (43940-46875)	141-149 (20500-21700)	395-399 (57250-57750)	214-216 (31055-31315)	
	24-28	25-27	2-3	65-75	5-7	13-14	42-56
			81×10^3 (11.7×10^6)		78×10^3 (11.3×10^6)		
	80-86	66-68	99-101	58.5-61.5	125-135	67-73	64-66
			124-126				
	127-131 (18420-19000)						
	≈10 (≈1500)						
	0.13(4)						
	50-64 (37-47)	55-65 (40-48)	14-24 (10-18)	65-73 (48-54)	15-25 (11-19)	82-100 (60-74)	96-104 71-77

4. Creep rate at a stress of 17.2 MPa (2500 lb in.$^{-2}$)
5. 10 mm sq. (0.394 in. sq.) unnotched specimen.
6. Equivalent to pattern maker's shrinkage.

3 BOUNDARY AND MIXED LUBRICATION

This manual is designed for bearings running under boundary or mixed (boundary/hydrodynamic) conditions. The lubrication regimes can be most easily discussed by reference to Stribeck curves (Figure 3).

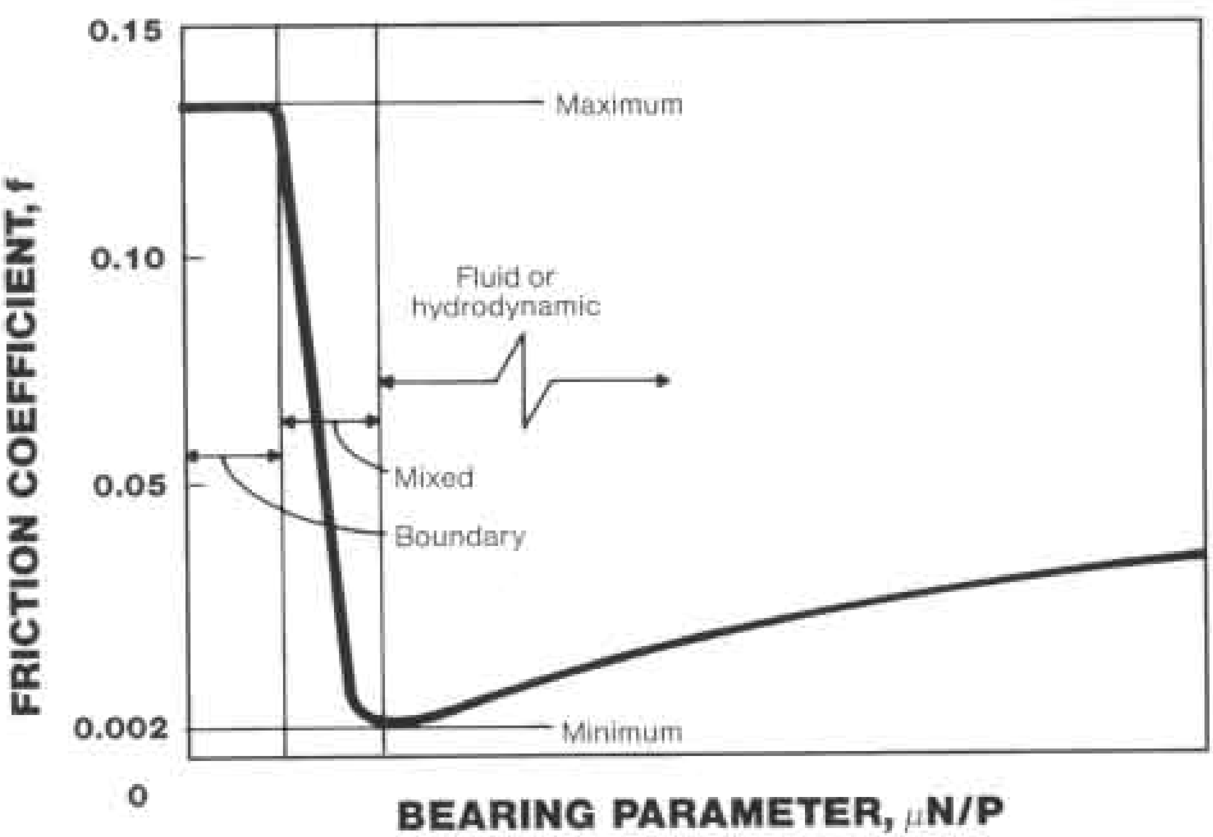


Figure 3 – Idealized Stribeck curve showing boundary (metal/metal contact), hydrodynamic (no metal to metal contact), and mixed regimes.

Stribeck curves consist of a plot of the friction coefficient, f, as a function of bearing parameter, $\mu N/P$, where μ is the dynamic viscosity of the lubricant at the operating temperature of the bearing (Pa s/lb s in^{-2}), N is the number of continuous revolutions per second (or m s^{-1}/ft min^{-1}) and P is the bearing stress (load) given in MPa (lb in^{-2}).

A Stribeck curve consists of three lubrication regimes viz:

(a) Boundary	—	some metal to metal contact separated by a thin film of lubricant and characterized by high friction independent of the bearing parameter.
(b) Hydrodynamic or Fluid	—	a complete thick film separation of the journal and bearing. Here the friction is dependent only on the shear properties of the lubricant.
(c) Mixed regime	—	a mixture of the above, characterized by increasing friction as the bearing parameter decreases, i.e. load increases, speed or viscosity decreases.

These three regimes are shown collectively in Fig. 3, which represents an idealized curve. The position of the Stribeck curve is very dependent on the roughness of the shaft, moving to higher values of friction and bearing parameter with an increase in roughness. Stribeck curves should ideally represent those conditions which follow the "run in" period, during which the shaft becomes polished. Most commercial, industrial bearings operate in the boundary or mixed regimes, or both, during their operating life. It is of importance that operating conditions be controlled to reduce the friction coefficient, f, thereby promoting savings in both wear rate and power requirements.

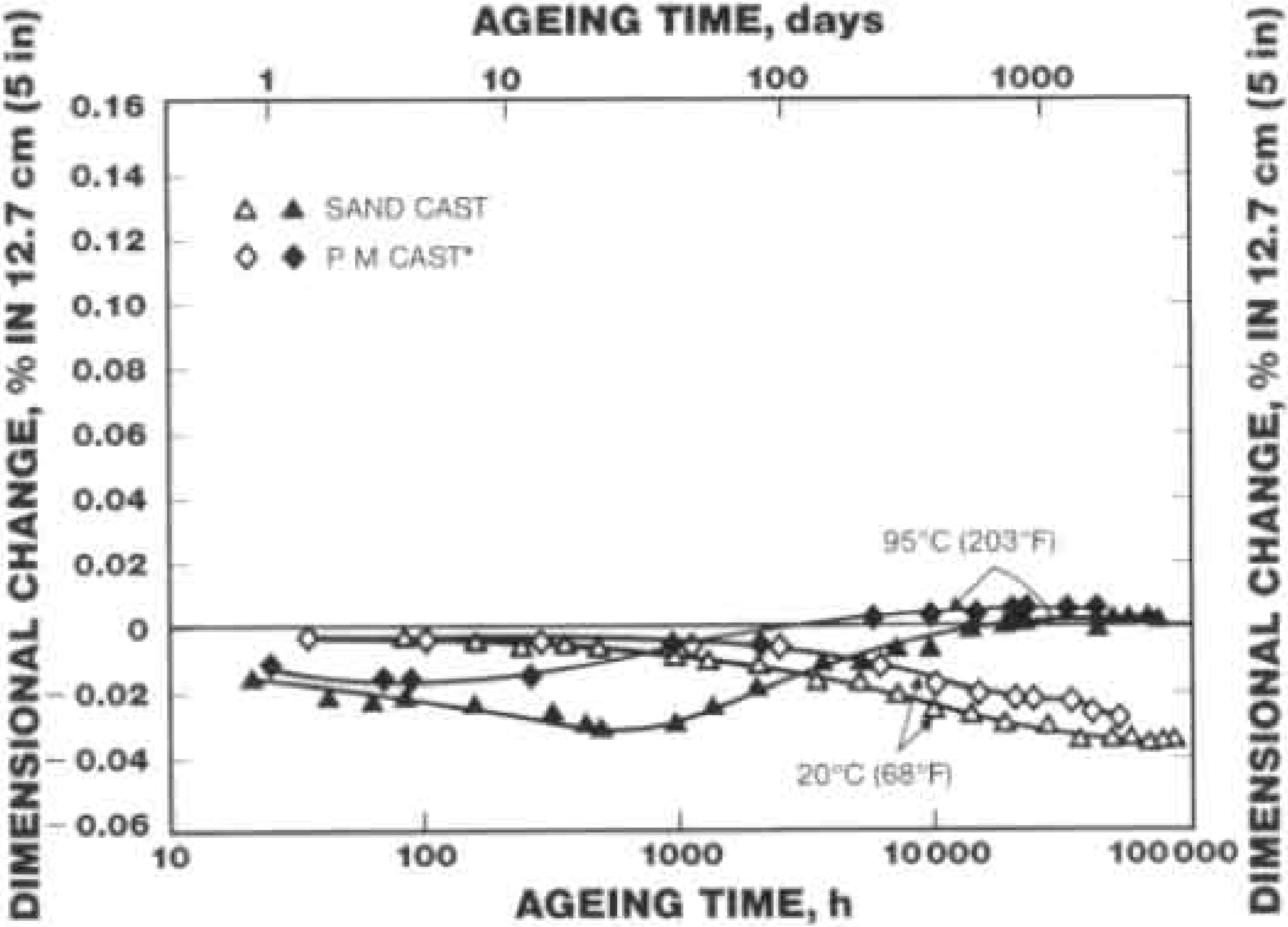
4 LUBRICATION / GREASE GROOVING

Standard greases normally used for bronze bearings are compatible with ZA alloys. Mineral oil based greases are best; those containing animal or vegetable oils are not recommended. The ZA alloys are attacked by strong acids or alkalis, hence the grease should have a pH between 6 and 9. Greases used can contain EP or non EP additives. Grease grooving is unnecessary for small diameter bearings [up to 2.5 cm (1.0 in.)]. For larger sizes grease grooving typical of bronze bearings can be employed (4). The grease , irrespective of the type, should be replaced on a regular basis, especially where wear debris production is excessive or the bearing is consistently run at high temperatures of 100°C (212°F) or more.

5 JOURNALS AND CLEARANCES

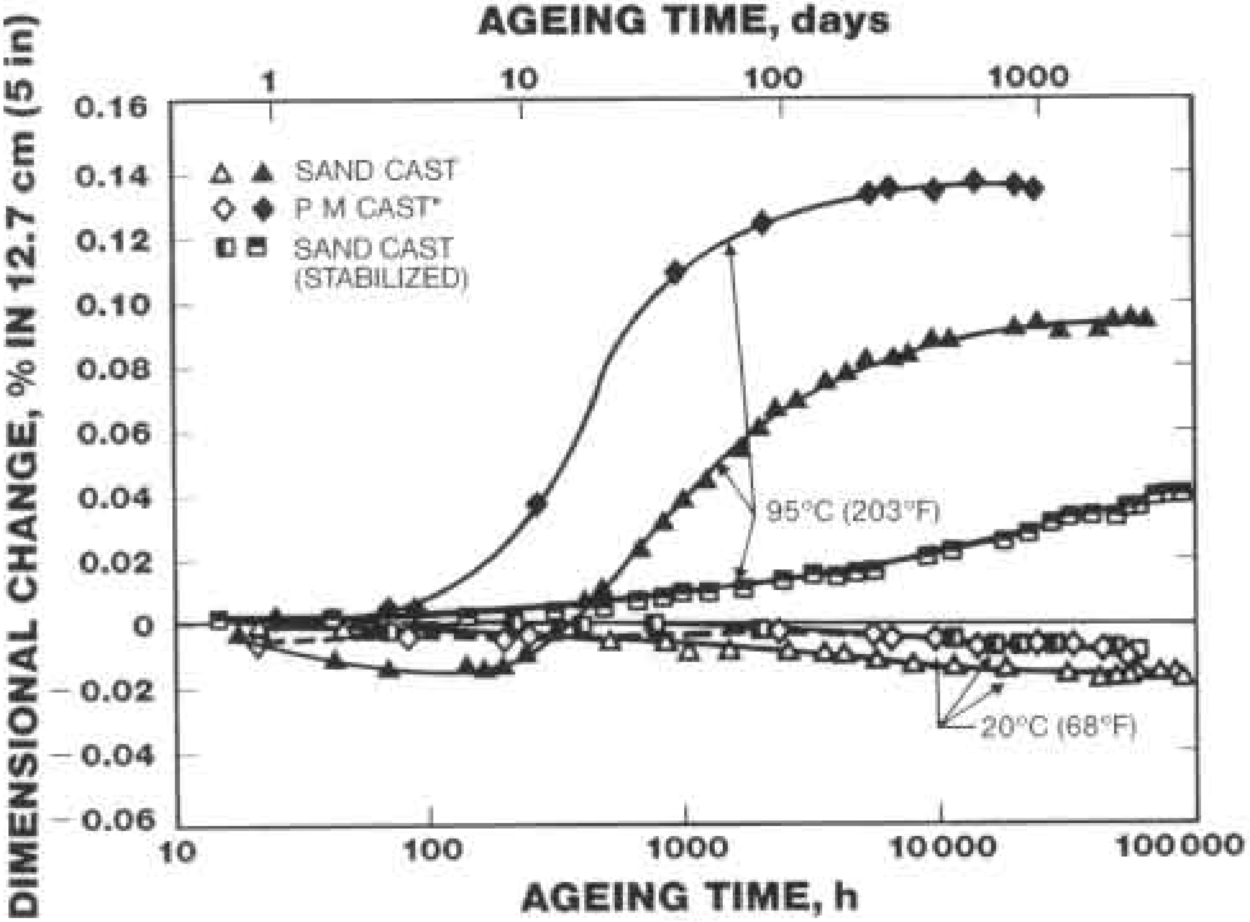
Generally, the journal (normally steel) should be approximately twice as hard as the bearing and a minimum of 80 BHN points harder than the bushing. The use of harder ($R_C \geq 40$) journals have been shown to benefit bearing wear performance when matched with the ZA-27 bearings. The journal surface is very important to the wear characteristics of the bearing. A smooth surface (0.4 − 0.6 μm/16−24 μin. CLA) is necessary for good wear performance. A surface roughness of 0.2 μm/8 μin. CLA or better (polished shaft) produces markedly superior wear performance.

The clearance for ZA alloy bearings run near room temperature is recommended at 0.0025 times the journal diameter. Enlargement of this clearance may benefit



(a)

bearing load capacity but will increase wear. At high temperatures, bearings secured by shrink fits should have clearances adjusted by a factor of 1.15, while for unrestricted bearings, a factor of 0.85 should be used. This also accommodates the volume increase shown by the ZA-27 alloy when aged rapidly at high bearing temperatures (Fig. 4).



(b)

*Approximately equivalent to continuously cast

Figure 4 — Linear dimensional change as a function of time for, a) sand cast and permanent mould (gravity die) cast ZA-12 and b) sand cast, sand cast and stabilized (12 h at 250°C (482°F), furnace cooled) and permanent mould (gravity die) cast ZA-27 at 20°C and 95°C (68 and 203°F).

6 BEARING FIXTURE AND WALL THICKNESS

Bearing fixture techniques follow those for bronze bearings. An interference fit of 0.0005 to 0.001 times the housing bore diameter is recommended. At higher temperatures, this interference fit should be increased by a factor of 1.4. The larger the bearing wall the smaller the interference fit required. Shrinkage fit can also be employed but care should be taken with handling the ZA alloys at the low temperatures required. At these low temperatures the alloys are brittle under impact loading.

Minimum bearing wall thickness should be calculated from:

$$\text{Minimum thickness} = 0.045D + 0.5 \text{ mm}$$

$$\text{or} \quad 0.045D + 0.02 \text{ in.}$$

where D is the journal diameter, mm (in.)

7 CONFORMABILITY / EMBEDDABILITY

The ZA alloys are hard in comparison to lead-tin bronzes but equivalent to aluminum bronze. Their conformability (ability to deform to accommodate journal misalignment) is better than bronze in view of the lower melting point of the alloys and the reduction in hardness with bearing temperature. Embeddability is also excellent and is comparable to C93200 bronze. However, as with all bearing materials, efforts should be exercized to prevent ingestion of larger dust or metallic particles which could result in rough running and wear of the bearings.

8 EMERGENCY RUNNING (ANTIGALLING)

The lubrication starvation or emergency running properties of ZA alloys are superior to lead-tin and aluminum bronzes. During such conditions, a thin film of zinc is smeared across the interface with the journal, thereby reducing friction and wear on the shaft.

9 CORROSION ASPECTS

In nearly all cases, bearing applications involve atmospheric exposure of the outer surface as opposed to complete immersion exposure. Little attack of the bearing/journal interface occurs unless the bearing receives no lubrication. The ZA-12 and ZA-27 alloys display good resistance to atmospheric corrosion. Corrosion rates are unlikely to exceed 15 μ m (590μ in.) per year, even in the most severe industrial and marine atmospheres, and may be as low as 1 μ m (39 μ in.) per year in rural conditions. Also, ZA-12 and ZA-27 alloys will offer good corrosion resistance in a variety of plant environments (e.g. the chemical and petrochemical industries, pulp and paper mills, waste water treatment plants) as long as the bearings are not directly exposed to corrosive solutions or gases.

The ZA alloys may experience galvanic corrosion if in contact with other metals. However, the degree of corrosion under atmospheric conditions is generally small and can be tolerated in many circumstances. On the other hand, coupling of the ZA alloys with other metals in a damp environment (e.g., underground applications) can lead to significant corrosion damage.

The ZA-12 and ZA-27 alloys will corrode appreciably in highly acidic and alkaline conditions. The recommended pH range of application is between 6.0 and 11.5, although the formation of protective films from salts in solution can broaden this range.

Susceptibility to intergranular corrosion in zinc aluminum alloys has been virtually eliminated by specifying low levels of impurity elements such as lead, tin and cadmium. No intergranular corrosion attack is to be expected under atmospheric exposure. However, some intergranular corrosion [depth of penetration of 0.02 to 0.4 mm (0.0015 to 0.02 in.) per year] may be experienced if the bearing is operated at temperatures of 60°C (140°F) or more in a highly humid (or aqueous) environment.

If conditions warrant, the outside of a ZA alloy bearing can be chromated, nickel and chromium plated or anodized for added protection.

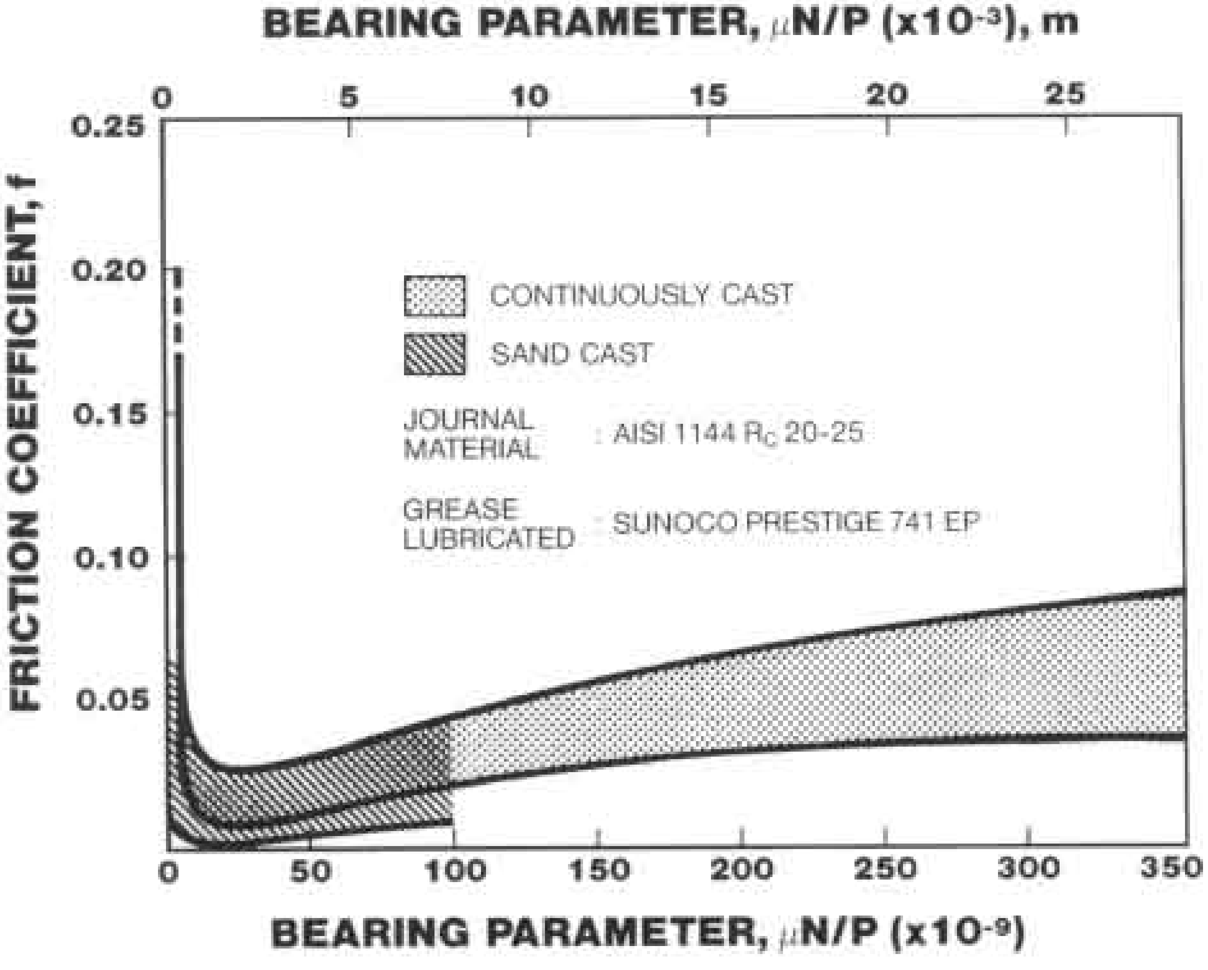
10 DESIGN CHARTS

The charts used for design of ZA bearings are as follows:

A. Stribeck curves
B. PV curves
C. Wear rate curves
D. Temperature curves

These data were generated using 2.54 cm (1.0 in.) ID, 4.42 cm (1.74 in.) OD (L/D = 1.0) concast and sand cast bearings under a variety of loads and speeds, together with several shaft and bearing conditions. The grease used was Sunoco Prestige 741 EP applied with an automatic feed set at 15 minute intervals. The charts shown are universal in nature and allow extrapolation to both larger and smaller diameter bearings with an L/D ratio in the range 0.5-2.0, but must be used with caution. They are, however, representative of ZA alloys in accordance with lead-tin bronze norms.

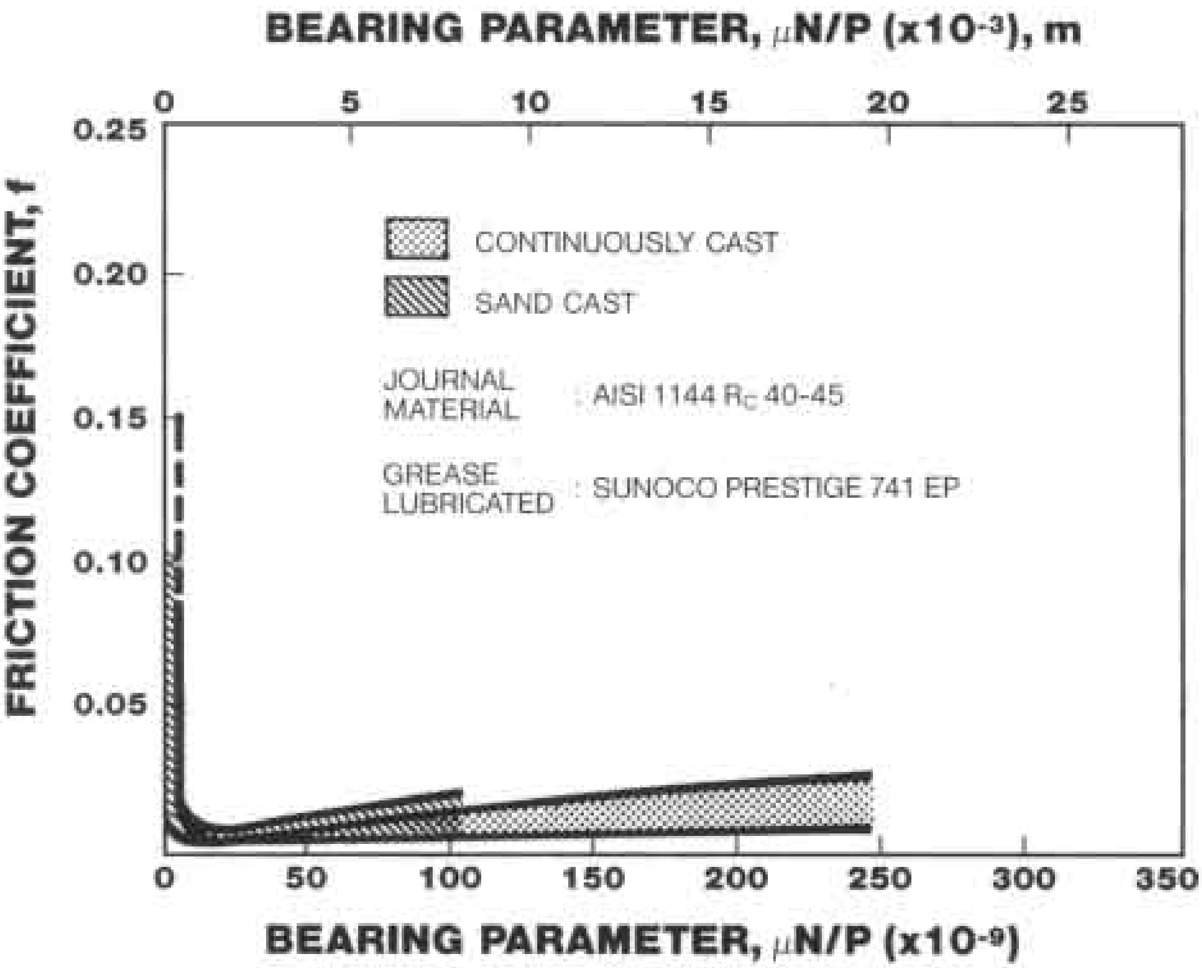
A. STRIBECK CURVES



(a)

Figure 5 – Stribeck curves for continuously cast and sand cast ZA alloys:
a) ZA-12/soft shaft

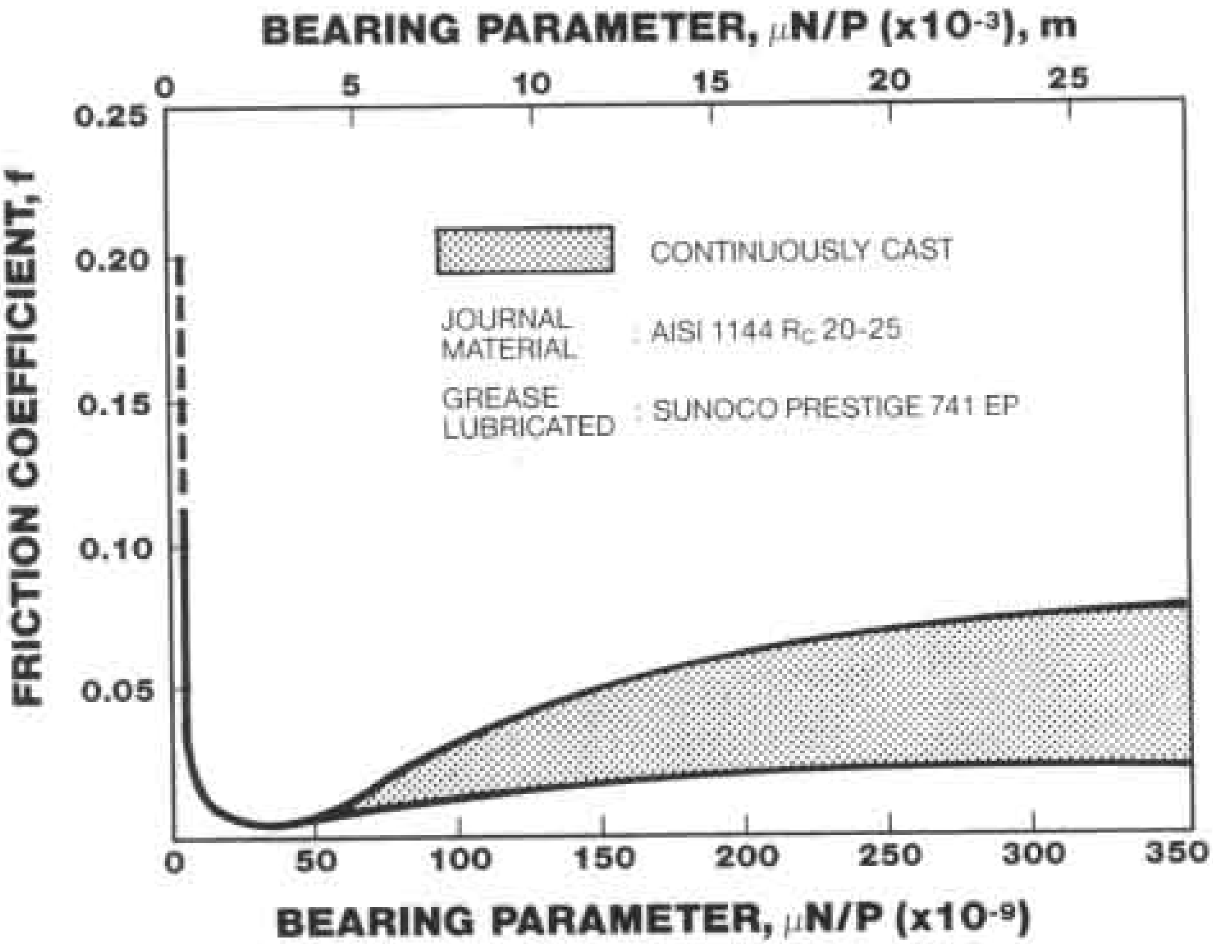
These charts are provided in Figure 5 for the ZA-12 and ZA-27 alloys respectively, both in the sand cast and continuously cast condition. The Stribeck curves show that low speeds and high loads (low bearing parameter) can be tolerated by the ZA-27 alloy without undue increases in friction, when combined with a hard shaft, than that possible for the ZA-12 and ZA-27 coupled with a soft shaft. The performance of ZA-27 decreases when used with a softer shaft, with the reverse being true for ZA-12. The best combination of shaft and bearing material is clearly critical so that recommendations for shaft hardness becomes a very important design criterion.



(b)

Figure 5 – Stribeck curves for continuously cast and sand cast ZA alloys:
b) ZA-27/hard shaft

The critical bearing parameter, that is, the low point of the Stribeck curve, is 1.6 for ZA-27 and 2.8 for ZA-12, while friction remains low for ZA-27 at higher bearing parameters. This gives an advantage in terms of emergency running at higher than normal speeds and for reduced power requirements and running temperature. This property is less if a soft shaft is used. The Stribeck curves for sand cast ZA-12 and ZA-27, combined with a soft and hard shaft respectively, lie below and to the left of those for continuously cast bearings. The frictional force measured is marginally lower for sand cast bearings when compared to concast bearings at a given bearing parameter. The minimum friction section of the Stribeck curve for sand cast ZA-12 bearings overlaps that recorded for the concast ZA-27 alloy, identifying similar behaviour of the two alloy/shaft combinations.



(c)

Figure 5 — Stribeck curves for continuously cast and sand cast ZA alloys:

c) ZA-27/soft shaft

N.B. All journals 0.4 – 0.6 μ m(16 – 24 μ in.) CLA roughness

B. LOAD-VELOCITY (PV) CURVES

Load-velocity curves consist of a plot of the bearing stress as a function of sliding speed. Dependent upon the data generated, regions corresponding to high friction (nominally > 0.1), high temperature (120°C (248°F) for ZA alloys), relative wear (high, medium) and hydrodynamic behaviour (low wear, low friction) can be identified. As for the Stribeck curves, the position of specific boundaries between different regions of behaviour is dependent on shaft condition, i.e. roughness and hardness. For example, a decrease in shaft roughness displaces both the hydrodynamic boundary and load capacity to higher stress and low speeds.

The PV curves generated for concast and sand cast ZA-12 and ZA-27 bearings are provided in Figure 6. Reference to Figures 6c and 6f for sand cast bearings provides

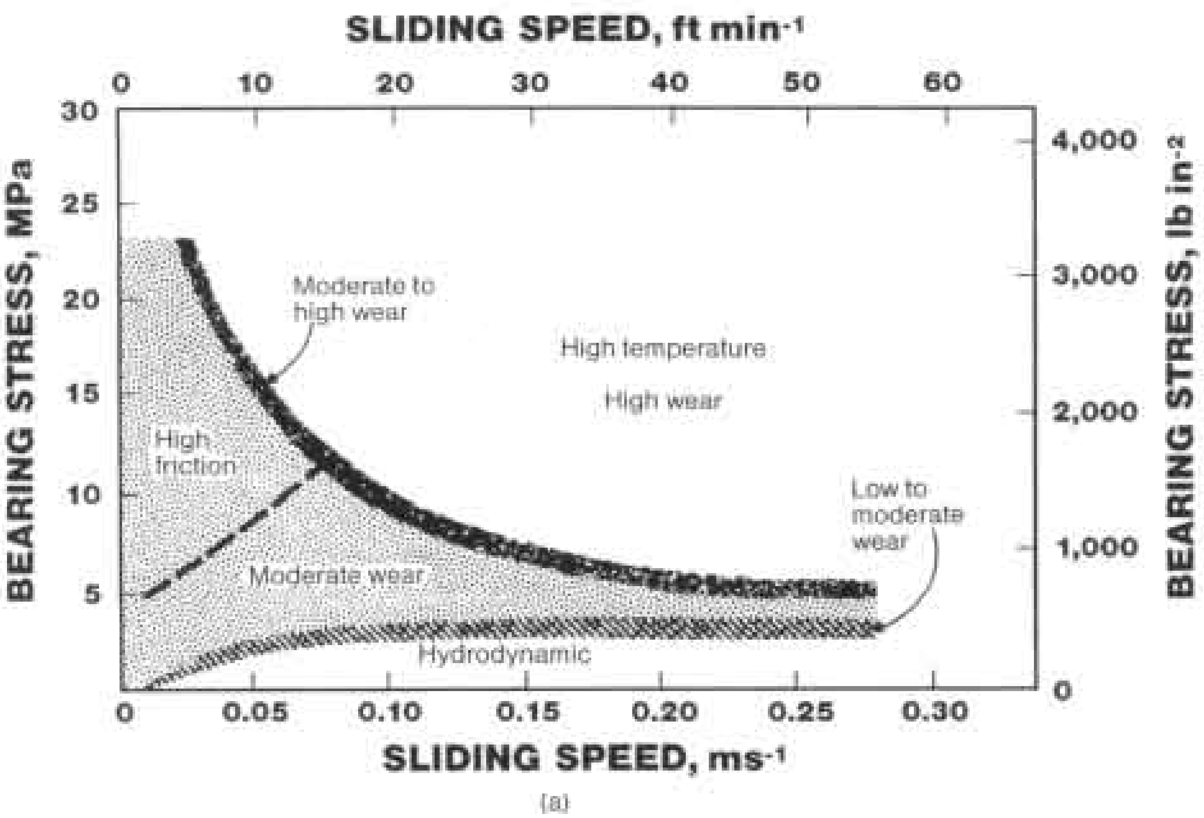


Figure 6 – Load-velocity (PV) curves for ZA alloys:
a) ZA-12 Concast/hard shaft

a comparison to PV curves for continuously cast ZA-12 and ZA-27 bearings run under the same journal conditions. The load capacity of sand cast bearings is increased over that for concast bearings equal to an amount between 6.9 — 13.8 MPa (1,000 — 2,000 lb in^{-2}) at speeds up to 0.20 m s^{-1} (40 ft min^{-1}). Beyond 0.20 m s^{-1} (40 ft min^{-1}) the difference in load capacity falls to approximately 3.5 MPa (500 lb in^{-2}). The reason for this behaviour is related to the increased creep resistance of sand cast vs concast alloys, particularly at bearing operating temperature. In addition, the boundary between moderate and low wear (hydrodynamic) is raised for sand cast ZA-27 bearings over that of concast bearings. No equivalent improvement was noted for the ZA-12 sand cast bearings.

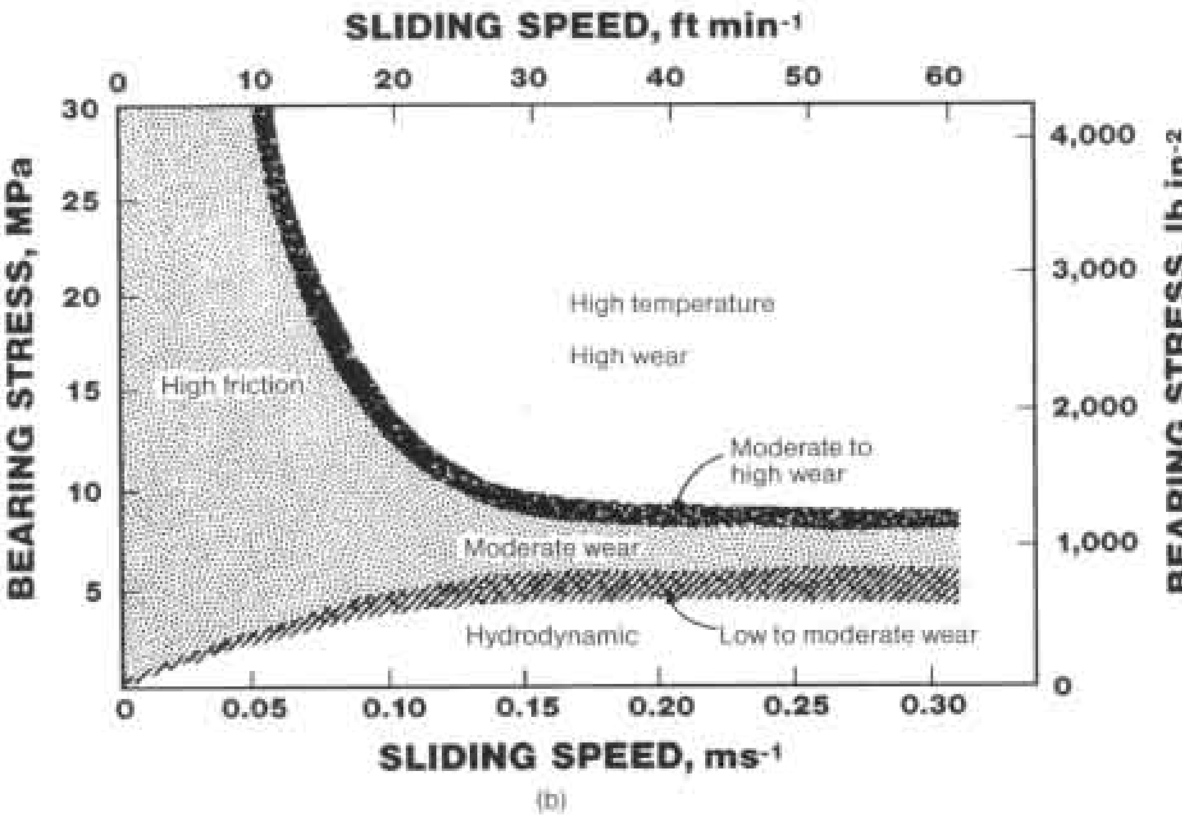
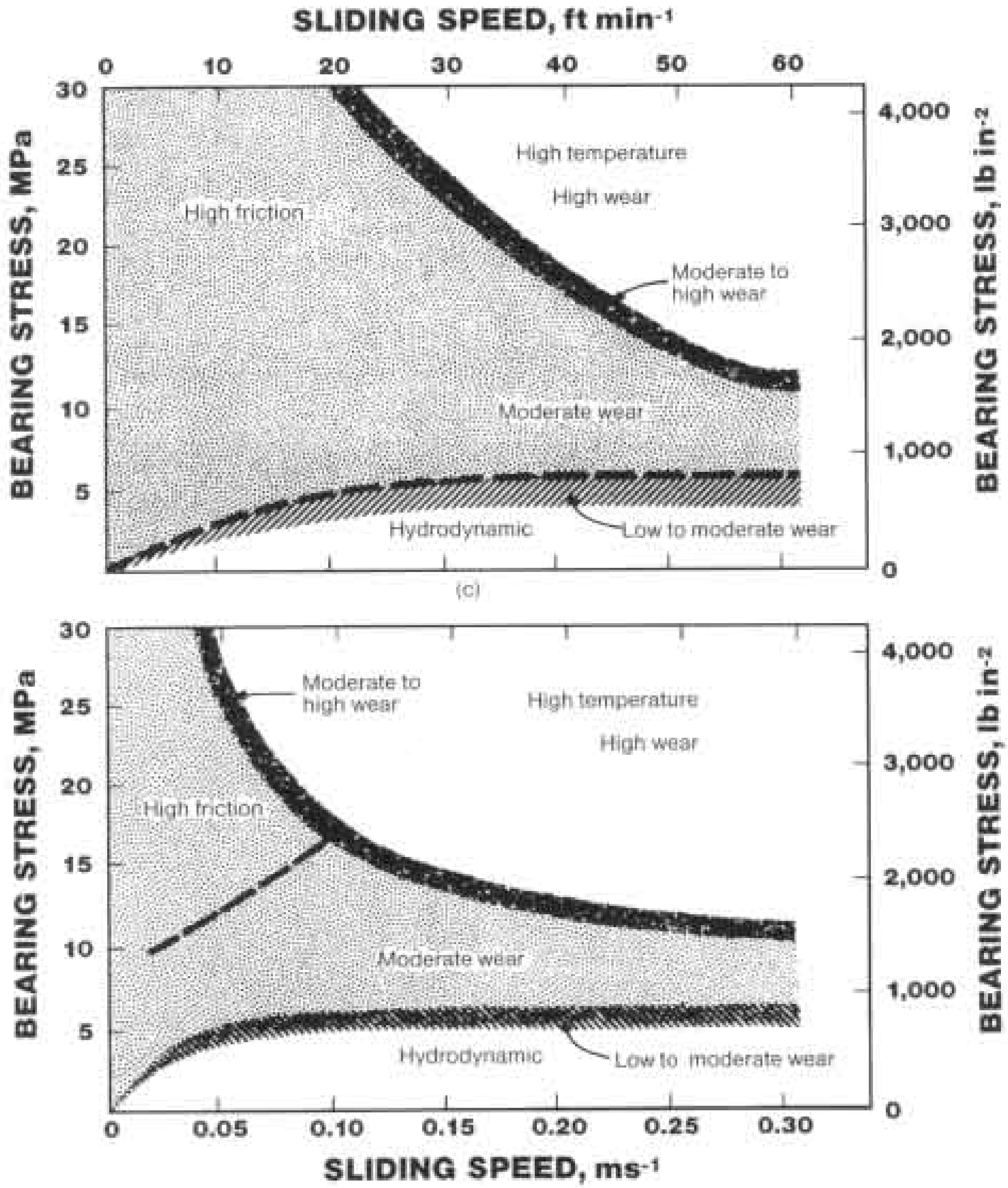


Figure 6 — Load-velocity (PV) curves for ZA alloys:

b) ZA-12 Concast/soft shaft



(d)

Figure 6 – Load-velocity (PV) curves for ZA alloys:
c) ZA-12 Sandcast/soft shaft d) ZA-27 Concast/hard shaft

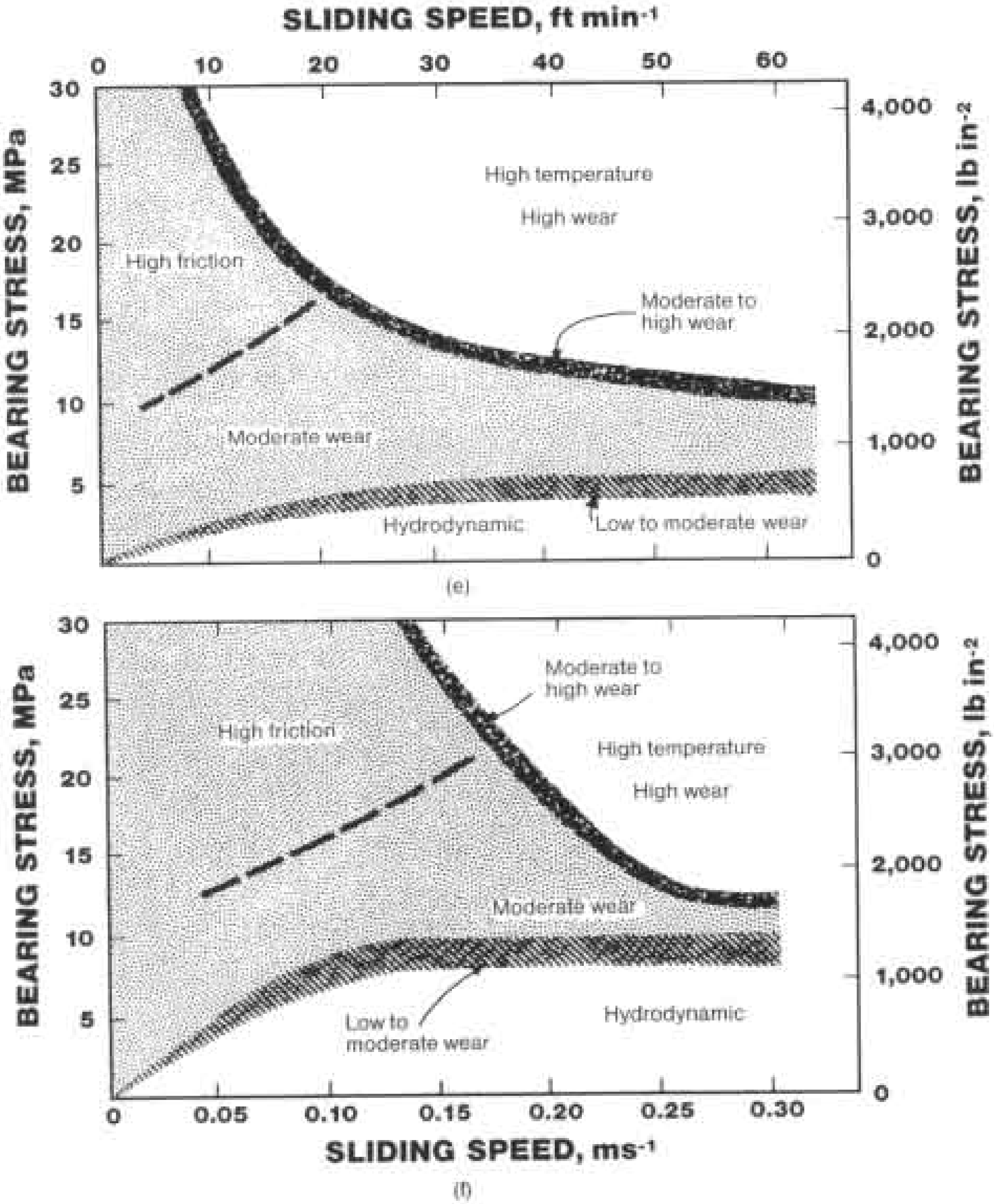


Figure 6 – Load-velocity (PV) curves for ZA alloys:
e) ZA-27 Concast/soft shaft f) ZA-27 Sandcast/hard shaft

C. WEAR RATE CURVES

Wear rate data for concast ZA-12 and ZA-27 as a function of bearing stress up to 8 MPa (1,160 lb in^{-2}) is provided in Figure 7. This diagram indicates ranges of wear for all material and shaft combinations tested. An increase in journal hardness, roughness and speed produces the highest wear rate shown for each individual alloy. Wear is represented here as a change in bearing wall thickness (wear depth) as a function of sliding distance.

As the load increases from 2 to 8 MPa (290-1,160 lb in^{-2}) the wear rate increases for all alloys. The difference between ZA-12 and ZA-27 is small but the absolute value is dependent on shaft hardness, being less than 15×10^{-9} m m^{-1} (in in^{-1}) at a stress of 2 - 6 MPa (290-870 lb in^{-2}).

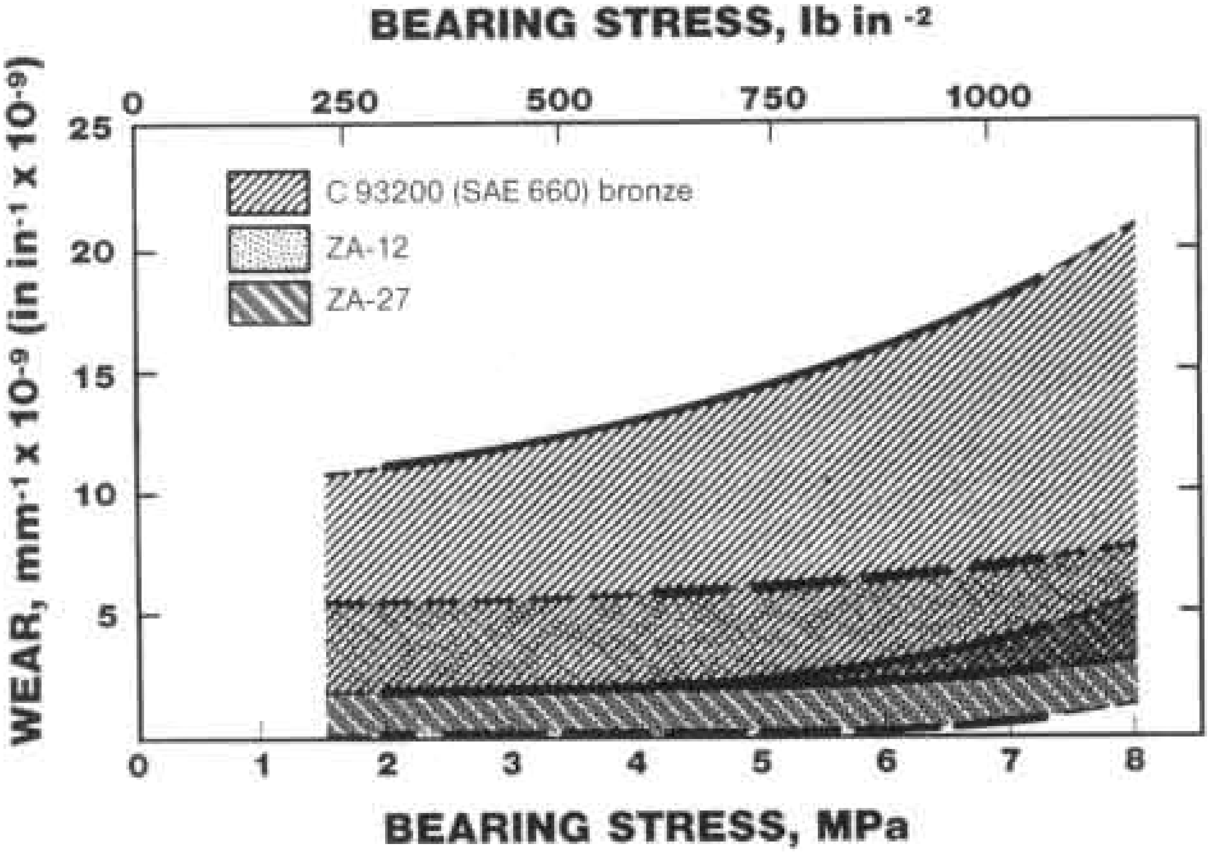


Figure 7 — Wear (dimensional change per unit of sliding distance) as a function of applied stress for 2.54 cm (1.0 in.) dia. concast ZA alloy and Pb-Sn bronze, grease lubricated, bearings. The degree of wear within the ranges shown is dependent on journal hardness, roughness and speed.

An increase in shaft hardness from soft (R_C 20 - 25) to hard (R_C 40 - 45) provides for improved wear resistance when coupled with ZA-27 but the reverse for ZA-12. In ZA-12, the wear rate measured can be up to 10 times higher with a hard shaft over that of a soft shaft. Shaft roughness is also an extremely important variable. Increased shaft roughness from 0.4 - 0.6 μ m (16-24 μ in) CLA to an average of 1.0 μ m (40 μ in) CLA produces 20% greater wear in ZA-12. Decreasing roughness from 0.4 — 0.6 μ m (16-24 μ in) CLA to 0.2 μ m (8 μ in) CLA produces up to 90% less wear in ZA-12 and 25% less wear for ZA-27.

Lower speeds produce increased wear when in the 0.013 — 0.04 m s^{-1} (2.6-7.9 ft min^{-1}) range, which is reduced at speeds up to 0.2 m s^{-1} (39 ft min^{-1}) coinciding with the low friction part of the Stribeck curves. However, a significant increase in wear occurs at higher speeds of 0.27 — 0.33 m s^{-1} (53-65 ft min^{-1}). This is abnormal in lightly loaded bearings when mixed and hydrodynamic behaviour is exhibited and which has been shown to lower wear. The limited data indicate that at these speeds and at higher loads, high temperatures result in lower lubrication viscosity, more metal to metal contact and enhanced wear.

Wear rate will vary depending on the application but sand cast ZA alloys are preferred where extreme conditions (high speed, high load, dirt particles) are to be expected.

D. TEMPERATURE CURVES

A plot of running temperatures measured on ZA alloys as a function of bearing speed and load is given in Figure 8. The thermal diffusivity of ZA alloys is approximately 3 times that of bronze and the friction marginally lower, thus running temperatures at equivalent loads are approximately half those recorded for bronze. Very high loads combined with low running speed are to be avoided if high bearing temperatures cannot be tolerated.

COMPARISON TO C93200 Pb-Sn BRONZE

Experimental data demonstrate that ZA alloy bearings have the following advantages over C93200 (SAE 660) lead-tin bronze bearings [1]:

- ZA bearings typically run with lower friction energy loss and at lower temperatures than C93200 bronze bearings under identical conditions of load, speed and journal.
- The load capacity of ZA bearings is equivalent or higher than for C93200 bronze bearings, particularly at higher speeds. Further, hydrodynamic

behaviour is extended to higher load in ZA bearings than in C93200 bronze at equivalent bearing speeds.

- The wear rate of ZA alloys is equivalent to or often much lower than C93200 bronze under the same conditions of load and speed.

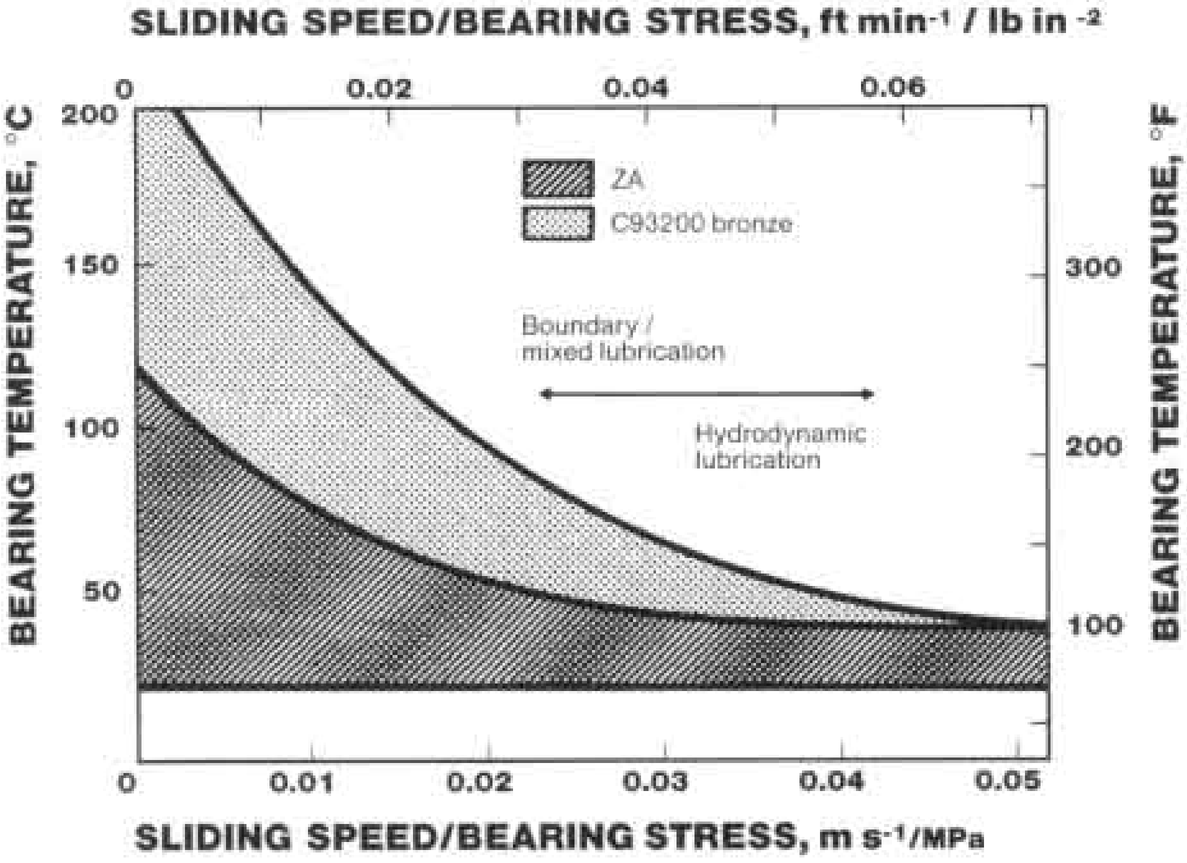


Figure 8 — Bearing temperature as a function of sliding speed/bearing stress for ZA alloys and C93200 bronze combined with hard and soft shafts. Temperature measurements based on 2.54 cm (1.0 in.) dia. bearings.

11 BEARING DESIGN PROCEDURE

EXAMPLE

The design for a new, heavy duty shunting locomotive calls for the 130 tonne load to be supported by eight, nominally 0.152 m (6.0 in.) dia., grease lubricated ZA bearings, run on 2 m (6.56 ft) dia. wheels. Running speed averages 10 km (6.25 miles) per hour for 3000 h in one calendar year. Bearing wear should be limited to <1% of bearing diameter between maintenance schedules of 1 year.

What alloy and bearing size should be used in this application?

SOLUTION

Step 1 ESTIMATION OF BEARING RUNNING TEMPERATURE

a) Sliding speed of bearing is given by:

$$\frac{D_1 \times S_T}{D_2}$$

where D_1 = Diameter of bearing, m (ft)
D_2 = Diameter of wheel, m (ft)
S_T = Speed of train — 10 km h^{-1} (2.78 m s^{-1}/547 ft min^{-1})

If $D_1 = 0.152$ m (6.0 in) } per
and $D_2 = 2$ m (6.56 ft) } specification

Bearing sliding speed (S_B) = 0.21 ms^{-1} (41.3 ft min^{-1})

b) Bearing stress, P, is calculated from the load distribution on each bearing and projected area.

Load per bearing = 130 tonne/8
= 16.25 tonne

Projected bearing area is given by L × D_1 where L is the bearing length and D_1 is the bearing diameter.

If $D_1 = 0.152$ m (6.0 in)
and assuming a trial value of L = 0.152 m (6.0 in) (L/D = 1.0), then bearing stress is:

$$= \frac{16.25 \text{ tonne}}{0.152 \times 0.152} \text{ or } \left(\frac{35{,}815 \text{ lb}}{6.0 \times 6.0}\right)$$

$$P = 6.897 \text{ MPa } (1000 \text{ lb in}^{-2})$$

c) Using Figure 8, bearing temperature is obtained by calculating the S_μ/P ratio.

$S_\mu/P = 0.030 \text{ m s}^{-1} \text{ MPa}^{-1}$ $(0.0413 \text{ ft min}^{-1} \text{ lb}^{-1} \text{ in}^2)$

Bearing temperature reaches a maximum of 40°C (105°F) for this application, which is acceptable.

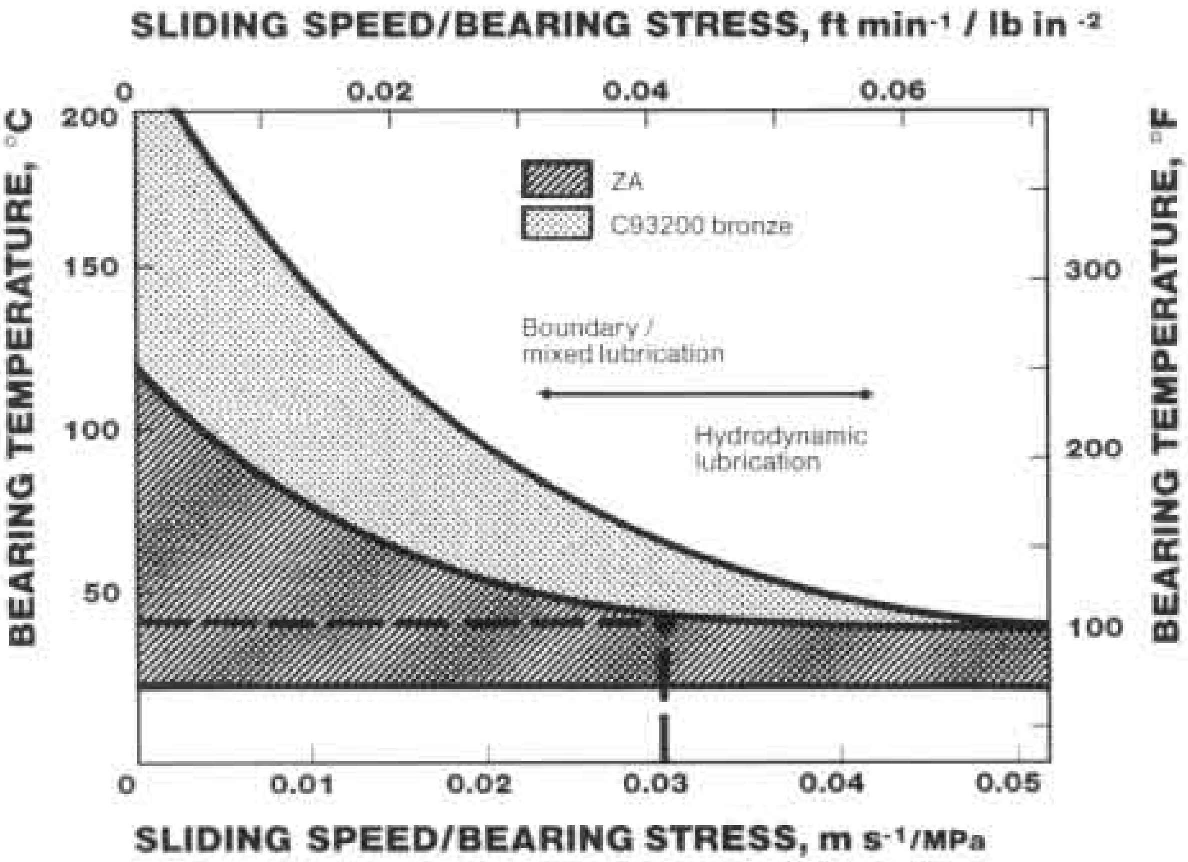


Figure 8 — Bearing temperature

Step 2 CHECK LUBRICATION CONDITION (STRIBECK CURVE)

Calculate the bearing parameter $\mu S_b/P$.

The value of viscosity, μ, is obtained from the temperature-viscosity curve for the grease used. Assuming the use of Sunoco Prestige 741 with EP additive for this application, μ at 40°C (105°F) is equal to 143×10^{-3} Pa s (2.0735×10^{-5} lb s in^{-2})

Since $S_B = 0.21$ m s^{-1} (41.3 ft min^{-1})
and $P = 6.897$ MPa (1000 lb in^{-2})
$\mu N/P = 4.35 \times 10^{-9}$ m (54.4×10^{-8} in)

Referring to Figure 5b, at an engine speed of 10 km h^{-1} (6.25 mph) the bearing will be operating in the mixed lubrication condition. For ZA-27 bearings a friction coefficient of 0.005 to 0.01 is indicated.

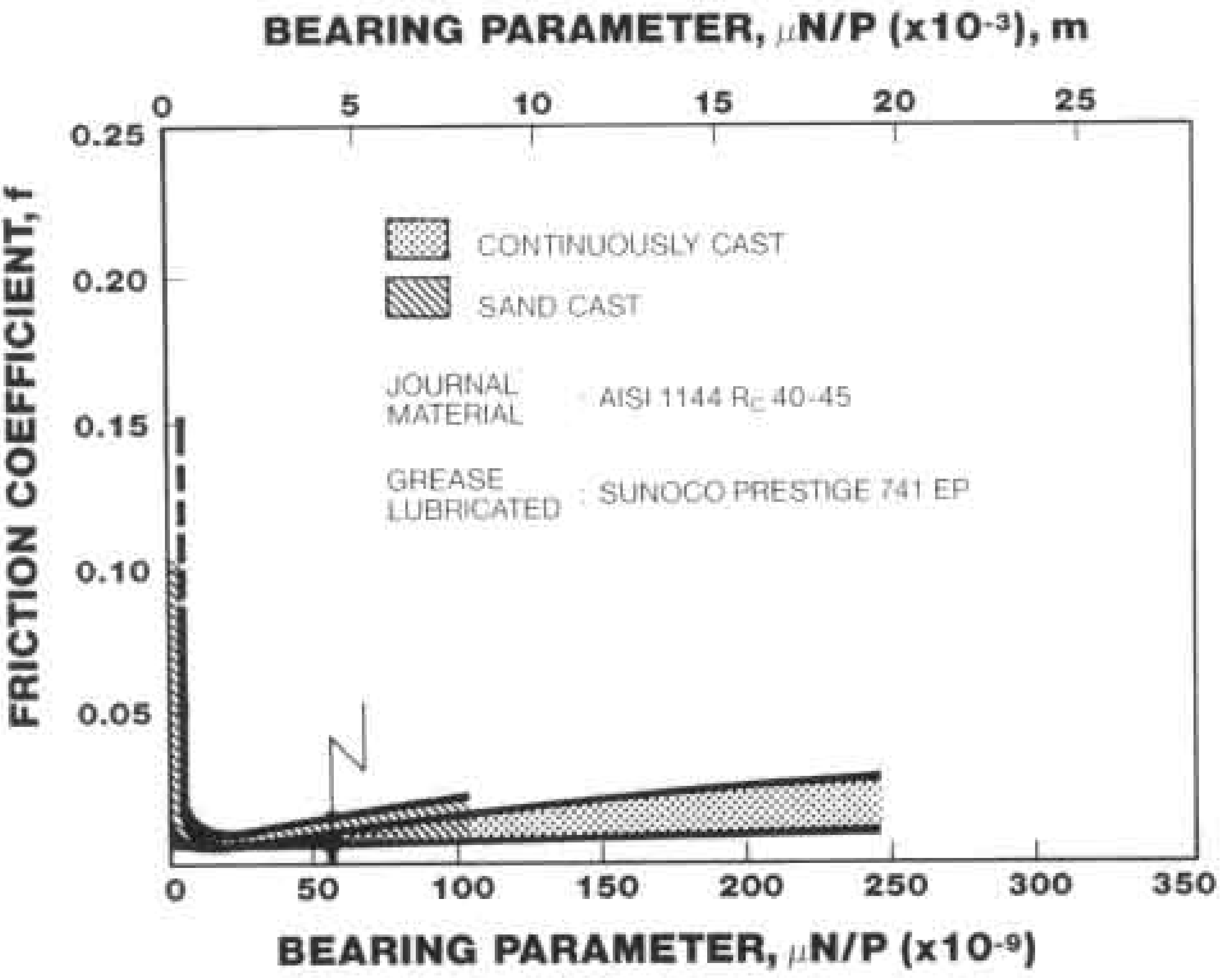


Fig. 5(b) — Lubrication Regime

Step 3 — CHECK LOAD CAPACITY RATING AND WEAR

a) Load capacity

Using Figure 6, the combination of bearing stress and speed reveals that the bearing will operate comfortably within the load capacity of the ZA-27 alloy but near the load capacity of ZA-12, particularly in the concast form.

b) Wear

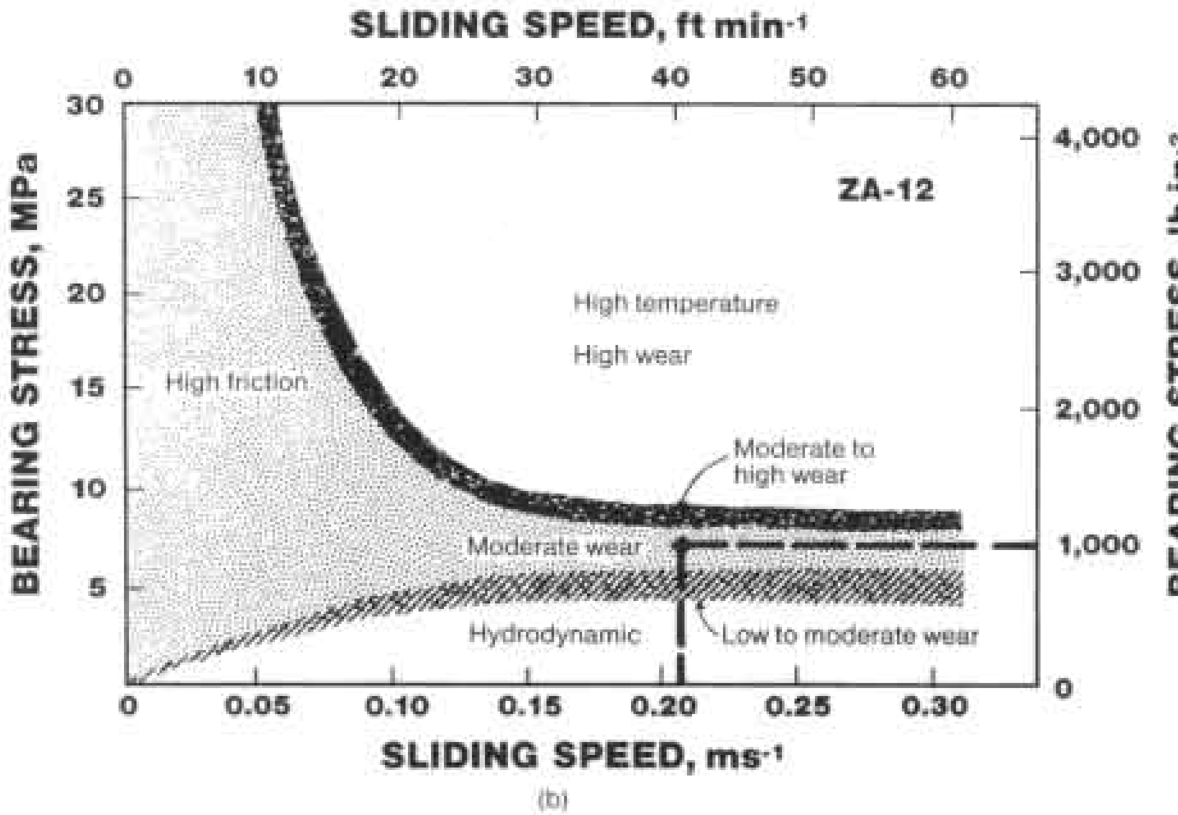
A bearing produced from ZA-27 alloy would show low to moderate wear rate, indicated in Fig. 7. At a bearing stress of 6.897 MPa (1000 lb in^{-2}), the wear rate ranges from 0.25 to 4 m m^{-1} (in in^{-1}) $\times 10^{-8}$.

For ZA-27 bearings, a hard shaft (R_c 40-45) of 0.6 μ m (24 μ in) CLA maximum roughness is recommended. Under these conditions a wear rate of 0.25 m m^{-1} (in in^{-1}) $\times 10^{-8}$ for sand cast ZA-27 to 0.5 m m^{-1} (in in^{-1}) $\times 10^{-8}$ for concast ZA-27 bearings is applicable.

In 3000 h of operation each bearing will undergo a sliding distance of:

$3000 \times 60 \times 60 \times 0.21$ meters

i.e. 2.268×10^{6} m (7.43×10^{6} ft)



(b)

Figure 6 – Load-velocity (PV) curves for ZA alloys:
b) ZA-12 Concast/soft shaft

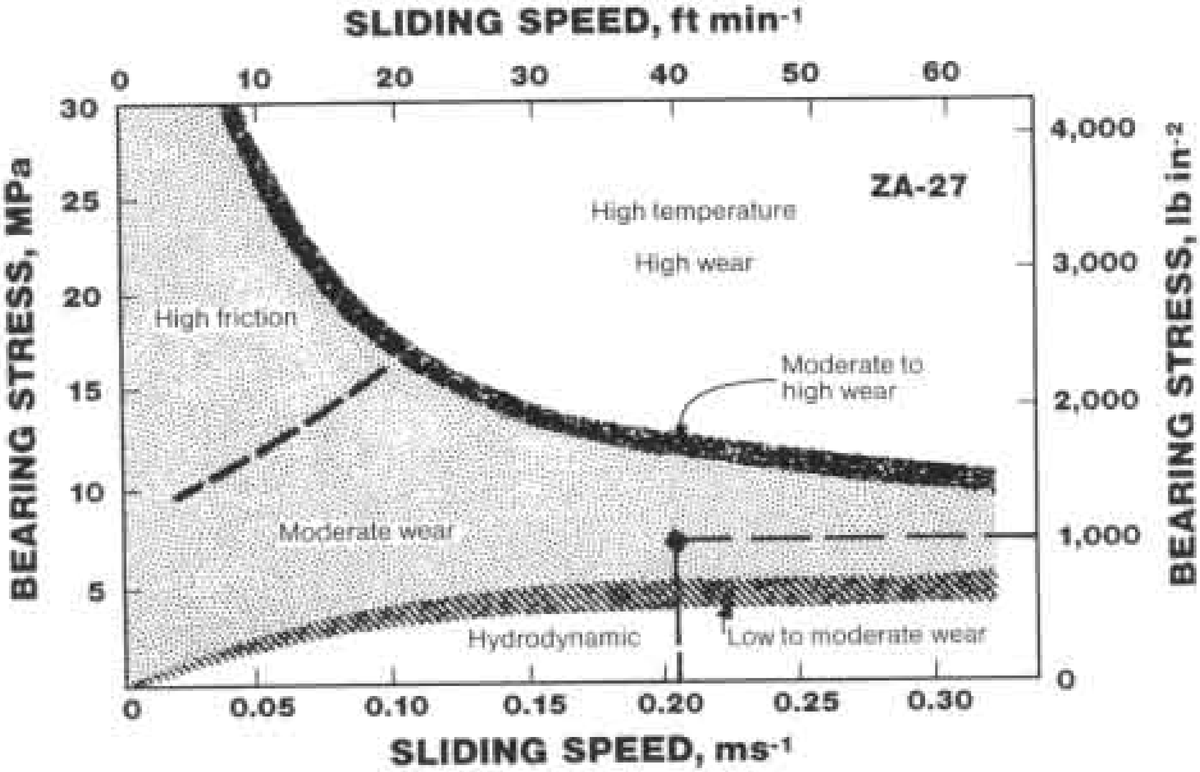
Assuming a safety factor of × 2, wear on each bearing made from sand cast ZA-27 will be:

2.268×10^{6} m $\times 0.25 \times 10^{-9} \times 2$

equal to 1.1 mm (0.0433 in)

or 0.7% of bearing diameter, which is within specification limits.

Note that the use of a polished shaft having a roughness of 0.2 μm (8 μin) CLA or better, or an increase in bearing size, would lower wear of the bearings still further.



(e)

Figure 6 – Load-velocity (PV) curves for ZA alloys:

e) ZA-27 Concast/soft shaft

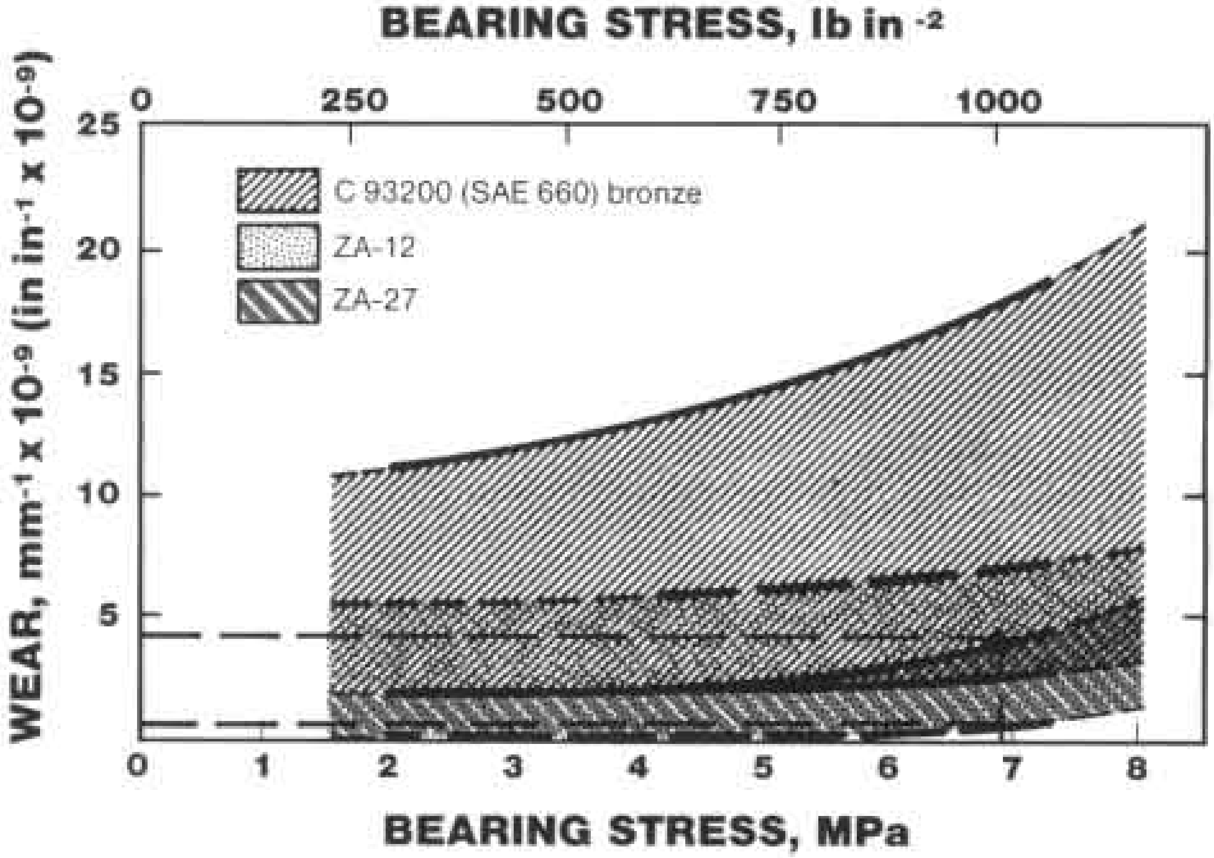


Figure 7 — Wear

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2. Barnhurst, R.J. and Farge, J.C., "Evaluation of ZA-12 and ZA-27 for Bearing Applications", Proceedings of the International Symposium on Zinc-Aluminum (ZA) Casting Alloys, Toronto, Canada, 1986. Published by C.I.M., Montreal, Canada.

3. Gervais, E., Barnhurst, R.J., and Loong, C.A., "An Analysis of Selected Properties of ZA Alloys", Journal of Metals 37 (11) 1985, 43-47.

4. Glaeser, W.A. and Dufrane, K.F., "Handbook on the Design of Boundary Lubricated Cast Bronze Bearings", Cast Bronze Bearing Institute 1978.

13. SUGGESTED READING

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Boundary Lubrication — An Appraisal of World Literature
Edited by F.F. Ling, E.E. Klaus and R.S. Fein.
ASME, New York 1969.

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Halsted Press, 1973.

Lubrication — A Practical Guide to Lubricant Selection
by A.R. Lansdown.
Pergamon Press, U.K. 1982.

BEARING APPLICATION QUESTIONNAIRE

This questionnaire can be used as a basis to assess the suitability of ZA alloys for a particular bearing application. A completed copy can be used during discussions with Noranda personnel at your office or via the telephone.

CONFIDENTIAL BEARING APPLICATION QUESTIONNAIRE

Company:
Division:
Address:

Telephone number:
Contact name and title:

CANDIDATE COMPONENT

Name:
Code number:
Function:

Number of bearings per unit:

Present:
Weight:
Approximate dimensions:

Estimated annual consumption:

Cost per component presently used:
Casting:
Machining:
As received, ready for use:

Availability of prints: ☐ yes ☐ no

noranda

AREAS OF PRESENT CONCERN OR IMPORTANCE

- ☐ Abrasion resistance
- ☐ Scoring resistance
- ☐ Temperature resistance
- ☐ Impact strength
- ☐ Compressive yield
- ☐ Fatigue
- ☐ Creep
- ☐ Load capacity
- ☐ Conformability
- ☐ Embeddability
- ☐ Corrosion
- ☐ Discharge pitting
- ☐ Cavitation
- ☐ Coefficient of friction
- ☐ Service life
- ☐ Emergency running
- ☐ Cost reduction

SPECIFIC PARAMETERS

PART 1. BEARING COMPONENT

Component design configuration:

Alloy type:

Bearing dimensions:
(I.D., bearing section, etc.)

Type and size of oil feed channels,
if applicable:

Operating load:

Average service life:

Apparent general mode of failure:

Remarks:

SPECIFIC PARAMETERS

PART 2. JOURNAL OR SHAFT

Material type:

Surface hardness:

Clearance:

Action; continuous
or oscillatory:

Speed of action, if applicable:

Arc and frequency of oscillation,
if applicable:

Remarks:

SPECIFIC PARAMETERS

PART 3. LUBRICATION

Brand name:

Lubricant type (oil, grease, etc.):

Weight or viscosity index:

Chemical type:

Additives (special in preblend, added on site, etc.):

Method of lubrication:

Closed or open cycle feeding:

Filtration:

Heat exchange cooling:

Service temperature:
- Entry:
- Exit:

Susceptibility to contamination:
- From exterior:
- From interior:

Contaminant type(s):

Lubrication regime:
- Boundary:
- Mixed:
- Thick film:

SPECIFIC PARAMETERS

PART 4. SERVICE CONDITIONS

Ambient service temperature: Minimum:

Maximum:

Bearing housing surface temperature:

Equipment operating temperature limitations:

Bearing cooling:

Type if present:

Bearing constraint material:

Operating risks: Impact:

High torque on startup:

Lubricant starvation on startup:

Electrical discharge pitting:

Cavitation erosion:

Embedment or scoring:

Remarks:

FINAL STATUS

Which ZA alloy was employed :

Final clearance tolerances employed:

Was the original bearing redesigned:

Details of redesign, if applicable:

Finished cost of ZA part:

Average service life of ZA part:

Mode of failure of ZA part:

Why was the part successful in ZA:

Other remarks: