2.6 Conclusion

Sintered bearings are used widely in instruments and general machinery, in which their self-lubricating characteristics and load-carrying ability is very desirable. When properly designed, they can be both economical and highly functional.

Their manufacturing method consists of briquetting the metal powder mixtures to the proper density. Subsequently, they are sintered for different duration subject to the temperatures. Sintered bearings are then sized to obtain the required dimensional characteristics. This is followed by inspection and impregnation with a lubricating oil.

3.0 PLASTIC AND NONMETALLIC BEARINGS

3.1 General Characteristics

Among the significant characteristics of plastic bearings, the following are noteworthy:

- Self-lubricating
- Low wear rates
- Relatively high performance rating (PV) among sleeve bearing materials
- Bearing O.D.'s compatible with standard sintered bronze sizes for upgrading existing equipment
- Kinetic and static coefficient of friction virtually the same under heavy loads
- Extremely low coefficient of friction, as shown in **Figure 3-1**
- Lightweight
- Ability to conform under load
- Resistance to chemicals

The design characteristics of plastic and nonmetallic bearings bear both similarities and differences relative to those of porous-metal bearings. This will now be described in greater detail.

3.2 Properties of Plastic and Nonmetallic Bearing Materials

Plastics (such as acetal, nylon, PTFE), carbon graphite and other nonmetallic materials have been increasingly used as self-lubricating bearings. Their composition has been refined over many years so as to obtain favorable bearing characteristics. These include low friction, corrosion resistance, ability to conform under load (plastic bearings), ability to function over wide temperature ranges and substantial load-carrying capability. Although temperature ranges, dimensional stability and load limitations of plastic bearings are in general less than for metallic bearings, plastic bearings are remarkably versatile and economical.

A summary of characteristics of representative plastic and nonmetallic materials has been given by *Machine Design* magazine (Vol. 54, #14, June 17, 1982, p. 132) with whose permission the following material is reprinted.

Phenolics: Composite materials consisting of cotton fabric, asbestos, or other fillers bonded with phenolic resin. The good compatibility of the phenolics makes them easily lubricated by various fluids.

They have replaced wood bearings and metals in such applications as propeller and rubber-shaft bearings in ships, and electrical switch-gear, rolling-mill and water-turbine bearings. In small instruments and clock motors, laminated phenolics serve as structural members as well as a bearing material. They have excellent strength and shock resistance, coupled with resistance to water, acid, and alkali solutions.

Some precautions must be observed with phenolic bearings. Thermal conductivity is low, so heat generated by bearing friction cannot readily be transmitted through the bearing liner. Consequently, larger, heavily-loaded bearings must have a generous feed of water or lubricating oil to carry away heat. Some swelling and warping of these bearings occurs in the larger sizes, so larger-than-normal shaft clearances are required.

Nylon: Although the phenolics have predominated in heavy-duty applications, they are frequently replaced by nylon, which has the widest use in bearings. Nylon bushings exhibit low friction and require no lubrication. Nylon is quiet in operation, resists abrasion, wears at a low rate, and is easily molded, cast, or machined to close tolerances. Possible problems with cold flow at high loads can be minimized by using a thin liner of the material in a well-supported metal sleeve.

Improvement in mechanical properties, rigidity, and wear-resistance is obtained by adding fillers such as graphite and molybdenum disulfide to nylon. While the maximum recommended continuous service temperature for ordinary nylon is 170°F, and 250°F for heat-stabilized compositions, filled-nylon parts resist distortion at temperatures up to 300°F.

PTFE: Has an exceptionally low coefficient of friction and high self-lubricating characteristics, resistance to attack by almost any chemical, and an ability to operate under a wide temperature range. High cost combined with low load capacity has frequently caused PTFE resin to be selected only in some modified form. PTFE is used as a bearing material in automotive knuckle and ball joints, chemical and food processing equipment, aircraft accessories, textile machinery, and business machines.

Although unmodified PTFE can be used to a PV value of only 1000, PTFE filled with fiberglass, graphite, or other inert materials, can be used at PV values up to 10000 or more. In general, higher PV values can be used with PTFE bearings at low speeds where its coefficient of friction may be as low as 0.05 to 0.1.

One bearing material combines the low friction and good wear resistance of lead-filled PTFE with the strength and thermal conductivity of a bronze and steel supporting structure. A plated steel backing is covered with a thin layer of sintered, spherical, bronze particles. The porous bronze is then impregnated with a mixture of PTFE and lead to provide a thin surface layer. Service temperatures of –330°F to +536°F are possible.

Woven PTFE fabrics are often readily handled and applied. With their resistance to cold flow, they are used as bearings in a wide variety of high-load applications as automotive thrust washers, ball-and-socket joints, aircraft controls and accessories, bridge bearings, and electrical switch gear. To provide a strong bond to either steel or other rigid backing material, a secondary fiber such as polyester, cotton, or glass is commonly interwoven with the PTFE. The woven fabric then is bonded to a steel backing.

Improved versions of this type of bearing have woven or braided “socks” (of PTFE and a bondable material). The bearing sleeve is then filament wound with a fiberglass-epoxy shell. These bearings have been reported to carry dynamic loads as high as 50000 psi.

Acetal: Components made from acetal rod are dimensionally stable even under extremely wet or humid conditions and will not swell like nylon in these conditions. Additionally, it resists most organic solvents. Natural white acetal is an USDA/FDA approved material for food processing applications. Acetal is relatively easy to machine and does not burr easily. Acetal is a generic descriptive name for two polymers: Celcon® – a copolymer made by Celanese – and Delrin® – a homopolymer made by E. I. DuPont Nemours. Both types are tough enough and strong enough to replace metal for many applications.

Acetron® NS: is a patented acetal-based compound containing special solid lubricants which help provide superior performance in bearing and wear applications. These lubricants are uniformly dispersed in the base acetal, providing a premium, internally lubricated compound with high Pressure Velocity (PV) capabilities, a low coefficient of friction, and an extremely good “k” factor.

Table 3-1 Wear Rate, Coefficient of Friction and Limiting PV Data

Acetal	Wear Factor “k” (1)	Comparative Wear Rate to Acetron® NS	Coefficient of Friction		Limiting PV (4)
			Static (2)	Dynamic (3)	
Acetron® NS	48	1.0	.18 – .19	.20 – .21	8750
Delrin AF Blend	57	1.2	.18 – .19	.19 – .20	8300
Delrin AF	65	1.4	.18 – .19	.19 – .20	11000
Delrin 500 CL (a)	176	3.7	.22 – .24	.23 – .25	3500
Acetron® GP	200	4.2	.22 – .25	.22 – .28	2700
Turcite A	213	4.4	.29 – .34	.20 – .23	6560

(1) Measured on 1/2” I.D. journal at 5000 PV (118 fpm & 42.2 psi)
K= h/PVT x 10^{-10} (in^3 min/ft lb hr) where:
h = radial wear (in)
P = normal pressure (psi)
V = sliding speed (fm)
T = test duration (hrs)
(2) Measured on thrust washer bearing under a normal load of 50 lbs. Gradually increasing torque was applied until the bearing completed a 90° rotation in about one second.
(3) Measured on thrust washer testing machine, unlubricated @ 20 fpm & 250 psi.
(4) Limiting PV (Test valued — unlubricated @ 100 fpm (lb ft/in^2 min)
(a) Equivalent to DSM’s MC® 901.

The additive system which delivers the lubrication is a patented composite. With it, the solid lubricants firmly locked in the acetal matrix are always exposed to the bearing surface. It’s this constant source of lubrication which enables Acetron® NS acetal to outperform other bearing materials. It also provides lubrication during break-in of bearings and for enhanced wear-resistance.

Because the acetal and solid lubrication do not absorb significant quantities of moisture, Acetron® NS acetal is stable in both wet and dry environments. It is highly recommended for precision, close tolerance parts.

The presence of the lubricant system in the acetal matrix also allows very free machining. The result is a very competitively priced product which will outperform other filled acetals in most bearing and wear applications, and give it a noticeable advantage over more expensive, premium-priced, internally lubricated acetal compositions.

Polyamide, Polysulfone, Polyphenylene Sulfide: High-temperature materials with excellent resistance to both chemical attack and burning. With suitable fillers, these moldable plastics are useful for PV factors to 20000 and 30000. Polyamide molding compounds employing graphite as a self-lubricating filler show promise in bearing, seal, and piston ring applications at temperatures to 500°F. Polyphenylene sulfide can be applied as a coating through use of a slurry spray, dry powder, or fluidized bed. These coating techniques require a final bake at about 700°F.

Ultrahigh-Molecular-Weight Polyethylene: Resists abrasion and has a smooth, low-friction surface. Often an ideal material for parts commonly made from acetal, nylon, or PTFE materials.

Carbon-Graphite: The self-lubricating properties of carbon bearings, their stability at temperatures up to 750°F, and their resistance to attack by chemicals and solvents, give them important advantages in fields where other bearing materials are unsatisfactory. Carbon-graphite bearings are used where contamination by oil or grease is undesirable, as in textile machinery, food handling machinery, and pharmaceutical processing equipment. They are used as bearings in and around ovens, furnaces, boilers and jet engines where temperatures are too high for conventional lubricants. They are also used with low-viscosity and corrosive liquids in such applications as metering devices or pumps for gasoline, kerosene, hot and cold water, sea water, chemical process streams, acids, alkalis, and solvents.

The composition and processing used with carbon bearings can be varied to provide characteristics required for particular applications. Carbon-graphite has from 5% to 20% porosity. These pores can be filled with a phenolic or epoxy resin for improved strength and hardness, or with oil or metals (such as silver, copper, bronze, cadmium, or babbitt) to improve compatibility properties.

3.3 Load Carrying Ability of Plastic Bearings

In **Section 2.2** of sintered metal bearings, the meaning and formulas for calculation of PV factor was dealt with.

For different plastic materials, the following values of PV and load capacities apply:

Table 3-2

Bearing Material	Load Capacity (psi)	Max. Temp. (°F)	Max. Speed (fpm)	PV Limit (Unlubricated)
Phenolics	6000	200	2500	15000
Nylon	2000	200	600	3000
PTFE	500	500	50	1000
Filled PTFE	2500	500	1000	10000
PTFE fabric	60000	500	150	25000
Polycarbonate	1000	220	1000	3000
Acetal	2000	200	600	3000
Carbon-graphite	600	750	2500	15000
Rubber	50	150	4000	—
Wood	2000	160	2000	12000

A PV limit of 15000 ordinarily can be used for dry operation of carbon bearings. This should be reduced for continuous running with a steady load over a long period of time to avoid excessive wear. When operating with liquids which permit the development of a supporting fluid film, much higher PV values can be used.

A hard, rust-resistant shaft with at least a 10 μin finish should be used. Hardened tool steel or chrome plate is recommended for heavy loads and high-speed applications. Steel having a hardness over Rockwell C50, bronzes, 18-8 stainless steels, and various carbides and ceramics also can be used.

Certain precautions should be observed in applying carbon-graphite. Since this material is brittle, it is chipped or cracked easily if struck on an edge or a corner, or if subjected to high thermal, tensile, or bending stresses. Edges should be relieved with a chamfer. Sharp corners, thin sections, keyways and blind holes should be avoided wherever possible. Because of brittleness and low coefficient of expansion (about 1/4 that of steel), carbon-graphite bearings are often shrunk into a steel sleeve. This minimizes changes in shaft clearance with temperature variations and provides mechanical support for the carbon-graphite elements.

The PV factor, used as a load-speed limit also provides a basis for estimating relative wear rates. The total volume of material worn away is approximately proportional to the total normal load multiplied by the distance traveled in a length of time.

Thus,

$$R = K(PV)\,T$$

where:

R = radial wear in a sleeve bearing (in)
K = wear factor (in^3•min/ft•lb•hr)
P = load (psi)
V = surface velocity (fpm)
T = time (hrs)

This equation does not always provide accurate absolute values for wear rate, but it is useful for estimating relative wear rates for alternative materials. In general, K wear values with fillers are lower than unfilled materials. If wear values are important for specific components, life tests should be made. These might employ moderately accelerated load and speed conditions to obtain a K value representative of the plastic, the shaft and its finish, and the application conditions.

K values should be increased by 50% for cast iron and bronze shafts, and more than 5 times with soft stainless steel or aluminum alloys. Increased surface hardness can markedly reduce wear, while surface roughness of the shaft often has an optimum value in the 4 to 14 μin rms range. Lubrication also has a pronounced influence on wear. With oil impregnation, wear rates commonly drop to negligible values with plastics, wood, and porous metals.

The wear factor K values are shown as follows:

Table 3-3

Material	Wear Factor K (in^3 min/ft lb hr)	
	Filled*	No Filler
Nylon	16×10^{-10}	200×10^{-10}
Polyester	20×10^{-10}	——
Polycarbonate	30×10^{-10}	2500×10^{-10}
Polyurethane	35×10^{-10}	——
Polypropylene	36×10^{-10}	——
Styrene Acrylonitrile	65×10^{-10}	——
Polysulfone	70×10^{-10}	——
Acetal	200×10^{-10}	65×10^{-10}

For 40 psi load at 2000 PV operating against carbon steel of hardness 20 Rc with a 6–12 μm finish.
*Filled with 30% (by weight) glass fiber, 15% (by weight) PTFE.

Comparative values for plastics often used as bearing materials are given in the following table:

Table 3-4

Property	Graphitar (Carbon-Graphite)	Oilon PV® 80 (TFE)	Rulon® (TFE)
Coefficient of friction	0.04 to 0.25	0.05 to 0.10	0.15 to 0.20
Temperature range	Cryogenic to 1000°F in some grades	–40°F to +250°F	–400°F to +550°F
Approx. max PV (unlubricated)	15000	18000	10000 (sleeve bearing)
Max. P	*	3000 psi	1000 psi
Max. V	*	1700 ft/min	400 ft/min
Recommended shaft surface finish	≤ 30 rms	*	8 to 32 rms
Recommended shaft clearance	0.003 in/in for most unlubricated applications	$(tw)10^{-4} + 0.004"$ t = temp. °F w= bearing wall thickness (in)	*
Typical elastic modulus	(0.5 to 3.5) x 10^6 psi	(3.5 – 3.8) x 10^6 psi	*
Tensile strength	1000 – 9500 psi, depending on grade	7200 psi	*

*Consult manufacturer

Data reprinted with the permission of the following manufacturers:

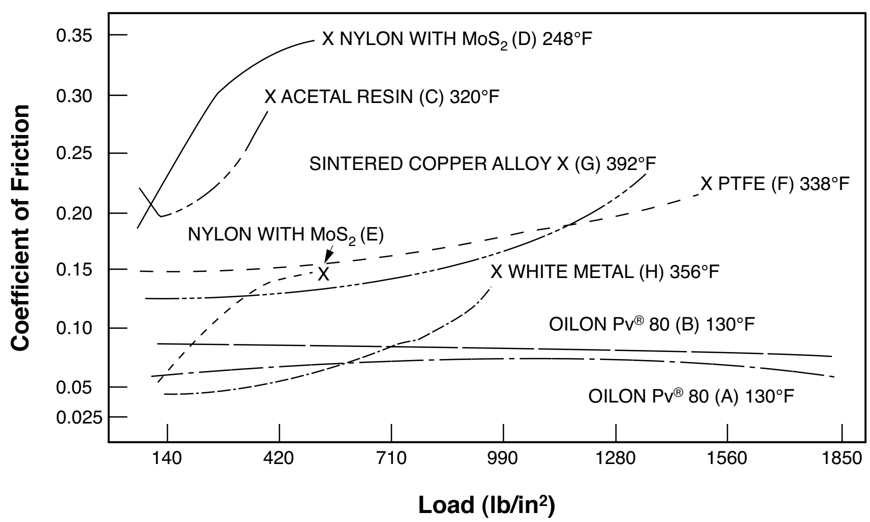
(i) "Graphitar" Wickes, 1621 Holland Ave., Saginaw, MI 48601;

(ii) "Oilon PV®" 80 Design Guide", TFE Industries, 148 Parkway Kalamazoo, MI 49006

(iii) "Rulon® Standard Stock Bearings, Engineering Manual, Cat. 75", Dixon Corp., Div. of Dixon Industries, Bristol, RI 02809.

3.4 Coefficient of Friction vs. Load for Various Materials

The coefficient of friction varies with the bearing unit load. The following graph depicts this relationship for various plastic materials.



(A) Oilon Pv® 80—Class I
(B) Oilon Pv® 80—Class II
(C) Acetal—Class I
(D) Nylon MoS_2—Class II
(E) Nylon MoS_2—Class I
(F) PTFE glass filled—Class II
(G) Oil Impregnated Sintered Copper Alloy— Class II
(H) White Metal—Class I

Class I: Grease applied externally, prior to start-up.
Class II: No grease applied prior to start-up.

Test conditions:
Velocity: 46 ft/min (350 rpm)
Load: 140 lbs/in^2, addition applied at 10 min. intervals
Dimensions of Test Specimen: 5/8" OD x 3/8" ID x 3/8" long
Mating Material: Steel 113° F HR-B 90

Fig. 3-1 Coefficient of Friction vs. Load

A comparison of frictional characteristics of various metallic and plastic materials is given in **Figure 3-1**. In some plastic materials, the coefficient of friction decreases with load, thereby greatly reducing or eliminating the stick-slip in the start-up of machinery.

In recent years, the properties of plastic bearing materials have been materially enhanced by the addition of fillers (such as fiber, powder, graphite and molybdenum disulfide) and composites (metal or other backings). If the cost is warranted, the mechanical properties of such bearings can be dramatically improved.

3.5 Example

A shaft of 1/2" in diameter is supported by two plastic bearings. The force equals 10 lbs. The bearing length is 3/4". The shaft rotates at 750 rpm.

$$PV = \frac{0.262 \cdot F \cdot rpm}{l} = \frac{0.262 \times 10 \times 750}{0.75} = 2619 \text{ fpm} \cdot \text{psi}$$

From the tables showing the maximum PV values, the proper material can be chosen. If the computed value exceeds the value in the table for the chosen material, the dimensions of the

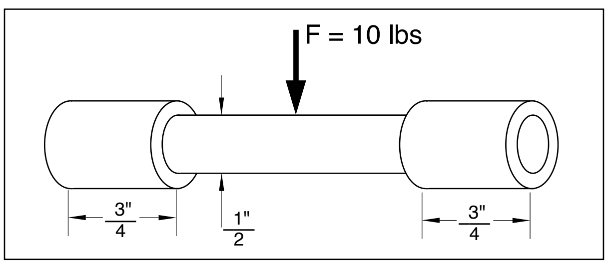


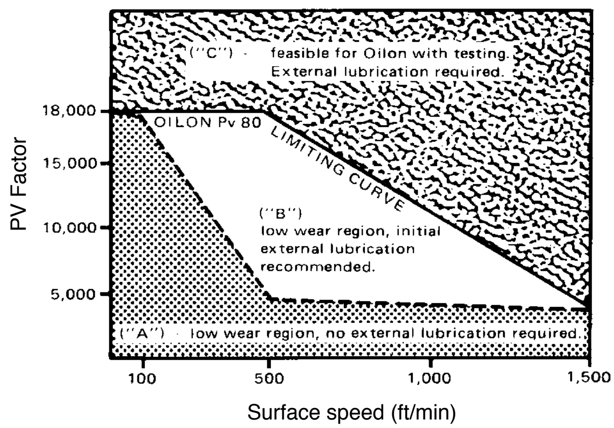
Fig. 3-2

shaft and of the bearing should be changed.

3.6 Lubrication

Lubricants reduce the static and dynamic coefficients of friction and permit materials to operate at higher PV's than without lubrication. While most plastics do not require lubrication, some type of lubricant will generally enhance bearing performance. In many cases, water will provide sufficient lubrication and cooling during bearing operation. At the time a plastic bearing is installed, it is a good idea to apply a light film of grease on the ID of the bearing prior to mounting on the shaft.

The effect of lubrication on the factor of a particular material (in this case, Oilon PV–80) is shown on the following graph:



(A) — low wear region, no external lubrication required
(B) — low wear region, initial external lubrication recommended
(C) — feasible for Oilon with testing. External lubrication required.

Fig. 3-3

3.7 Conclusion

Plastic and nonmetallic bearings are widely used in appliances, toys, general machinery and applications ranging from cameras and toys to office machinery and automobiles. When properly designed, their light weight and economy can be highly attractive.

Calculations of bearing loads, as shown in the example, are also applicable on plastic and nonmetallic bearings.

EQUIVALENT PRECISION CLASSES OF DIFFERENT STANDARDS

ABEC	RBEC	ISO	DIN
1	1	0	Normal
3	3	6	P6
5	5	5	P5
7	None	4	P4

ABEC – Anti-Friction Bearing Manufacturers Association (Ball Bearings)
RBEC – Anti-Friction Bearing Manufacturers Association (Roller Bearings)
ISO – International Organization for Standardization
DIN – Deutsche Industrie Normen