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Poly(amide-imide) Polymers – Properties, Processing Techniques, and Bearing Performance

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EACH MODEL YEAR automotive design engineers face a new set of constraints within which they must design their product. Historically these contraints have resulted in a greater need for weight savings, higher engine compartment temperatures, and a greater need for product reliability. These increasingly demanding requirements have, in turn, resulted in an intensified search for design concepts, fabricating techniques, and new materials.

Melt processable poly(amide-imide) resins, one of several high performance engineering resins which have been introduced to the marketplace during the last few years, allow the design engineer to resolve economically many of the problems he faces in friction and wear components and increasingly severe under-the-hood environments.

HISTORY

Melt processable poly(amide-imide) polymers are highly aromatic resins with the basic structure shown in Fig. 1.

Polymers of this type have been used commercially for several years as solution-applied magnet wire insulation, laminating varnishes, and high temperature decorative coatings. In 1972, a compression moldable poly(amide-imide) was introduced to the marketplace as Torlon* 2000, which was immediately accepted for specialized aerospace applications.

However, applications for this polymer were limited by its intractability and resultant relatively high finished product cost. Torlon 3000T and 4000T were developed to satisfy the need for a more tractable high performance compression molding resin. The introduction in 1973 of Torlon 4002, an extrudable poly(amide-imide), and Torlon 4200, which could be injection molded, greatly reduced finished part cost and brought these polymers within the realm of consideration for automotive applications on a cost/performance basis.

PHYSICAL PROPERTIES

The physical properties of poly(amide-imide) resins are some of the highest available in unreinforced plastics. The data in Table 1 were obtained using ASTM test methods, where applicable, on compression molded samples. Particularly note-

*Amoco Chemicals Corp. trademark.

ABSTRACT

The properties offered by poly(amide-imide) molding resins allow design engineers to consider plastics for applications formerly considered too severe for polymers, and allow plastics to penetrate markets for fluid valves, bearings, gears, and other functional parts which, until this time, have primarily been the province of metals.

In addition, these resins can offer a practical substitute for other plastics which must be replaced as the conditions under which they must perform exceed their inherent capabilities.

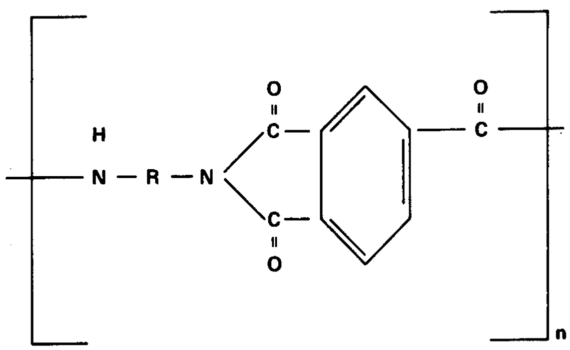

Fig. 1 - Structure of amide-imide polymers

worthy are the high tensile strength, flexural modulus, impact resistance, and low thermal conductivity and coefficient of thermal expansion exhibited by Torlon resins.

Test data as presented for 500°F are meaningful for Torlon 2000, 3000, and 4000 series polymers, since they retain over 90% of their initial physical properties after aging 2000 h at this temperature.

PROCESSING CHARACTERISTICS

For the manufacture of prototypes, Torlon 2000, 3000, and 4000 resins are compression moldable at temperatures of 620-650°F and at pressures of 3000-4000 psi. The properties obtained via compression molding are representative of those obtained by extrusion, but the properties of a sample compression molded from Torlon 4000 are 10-20% higher than can be expected in a part injection molded from Torlon 4200.

Stock shapes may be extruded on low shear, vented equipment from Torlon 4002. Stock temperatures of approximately 640°F are desirable for most applications, and barrel temperatures of about 600°F can be satisfactorily used. Die design is extremely important for the production of quality stock shapes, and streamlining is highly recommended. Optimum physical properties are obtained by postannealing the extrudate, and inferior product can result if the moisture content of the extruder feed is too high.

Parts can be rapidly machined from rod stock manufactured using Torlon 4002 on automatic equipment without the use of lubricants. Lubricants can be used, however, to reach maximum cutting speeds and to reduce tool wear.

For complex shapes produced in large volume, injection molding offers the most attractive economics. Torlon 4200 can be relatively easily processed on most of the injection molding machines produced in the last few years, but optimum properties are obtained using machinery capable of high injection speeds and pressures. In general, injection pressures of at least 20,000 psi are required, and barrel temperatures of 650-700°F are necessary. Although mold temperature is somewhat part-specific, mold temperatures of around 400°F are commonly required for parts with thin sections and long flow distances or requiring a high quality surface. Cycle times are usually very short. Postannealing of finished parts is recommended to develop optimum physical properties.

Although fillers and additives do alter processing conditions somewhat, Torlon resins with filler levels of up to 50% have been successfully processed by each of the above methods. With the exception of many fluorocarbon systems, most fillers are wetted by the polymer and do not degrade composite properties until high loadings are reached.

BEARING PROPERTIES

Many plastics have been and are being used in nonlubricated bearing applications: acetals, polyethylene, polyamides, polyesters, and many others, but in terms of high performance requirements, polytetrafluoroethylene (PTFE) and pyromellitic dianhydride (PMDA) type polyimides have been the materials of choice. Where lubrication is possible, however, these latter materials cannot generally compete with sintered bronze or other metal bearings on the basis of their cost/performance profile.

In addition, despite their generally superior performance as bearing materials, both PTFE and PMDA polyimides have serious shortcomings. PTFE is difficult to fabricate and exhibits creep or cold flow under load, thus limiting its operating range. PMDA polyimides are inherently more expensive and more difficult to fabricate than can be tolerated by most designers or fabricators for most applications. For these reasons, they have only been made available on a limited basis and at high cost.

Poly(amide-imide)-based bearing formulations have been developed which offer far greater resistance to cold flow than PTFE and easier processability and lower cost than PMDA polyimide resins. The basic Torlon resins have a relatively high compressive strength, and they resist creep even at high temperatures and even when filled with such materials as PTFE, graphite, molybdenum disulfide, and other dry lubricants.

The thermal stability of Torlon resins is excellent, thus minimizing polymer breakdown due to the high point temperatures reached during bearing use, and the good elongation of the resin limits cracking or bearing failure due to deformation. Table 1 presents the salient physical properties of Torlon 2000 molding resins filled with various additives to increase lubricity, hardness, compressive strength, and/or thermal conductivity. The effect of fillers on Torlon 3000 and 4000 type resins is roughly similar.

Since Torlon resins are resistant to most organic and inorganic systems, including aromatic and aliphatic hydrocarbons and fluorinated and chlorinated solvents, they can be used in lubricated, as well as nonlubricated, systems and in chemical environments which would rapidly eliminate any lubricated bearing from consideration. The friction and wear characteristics of Torlon-based bearing formulations are generally grossly improved by the presence of a lubricant.

Although Torlon resins, when used by themselves, exhibit good friction and wear properties, bearing performance can be greatly enhanced by the inclusion of minor amounts of PTFE, graphite, molybdenum disulfide, or other solid lubricants into the resin matrix.

Several companies have developed blends for bearing produc-

Table 1 - Typical Properties of Amoco Torlon 2000 Polymer (With and Without Fillers)

Test	ASTM Test Method	Torlon 2000 (Unfilled)	5% TFE Filled Torlon 2000	10% TFE Filled Torlon 2000	10% Graphite Filled Torlon 2000	10% TFE and 5% Graphite Filled Torlon 2000	25% Calcium Silicate Filled Torlon 2000	50% Calcium Silicate Filled Torlon 2000	25% Aluminum Filled Torlon 2000
Tensile strength, psi	D-638								
73°F		13,300	10,500	8,500	13,000	8,800	13,100	11,300	13,130
300°F		11,700	8,800	6,100	10,300	6,200	11,100	8,000	11,730
500°F		8,900	4,600	2,100	5,200	3,000	6,500	4,800	4,000
Elongation–73°F, %	D-638	2.5	2.1	2.0	3.4	2.2	2.3	2.1	3.0
Flexural strength, psi	D-790								
73°F		23,400	20,800	13,100	22,100	14,900	24,200	21,500	22,100
300°F		18,400	15,600	11,000	15,400	12,160	17,200	15,200	19,000
500°F		14,200	9,600	5,800	7,700	6,200	10,100	7,300	7,900
Flexural modulus, psi x10^6	D-790								
73°F		0.70	0.66	0.58	0.71	0.60	1.15	1.13	0.79
300°F		0.54	0.47	0.44	0.55	0.48	0.48	0.89	0.67
500°F		0.45	0.46	0.38	0.50	0.41	0.47	0.73	0.48
Compressive strength–73°F, psi	D-695	35,000	33,860	30,500	33,860	36,840	41,500	46,700	37,190
Shear strength–73°F, psi	D-732	18,800	5,300	5,100	14,550	6,150	15,600	12,800	19,300
Impact strength (Izod-notched), $\frac{\text{ft-lb}}{\text{in}}$	D-256	0.7	0.6	0.6	0.8	0.8	0.6	0.5	0.9
Specific gravity	D-792	1.41	1.44	1.46	1.45	1.49	1.58	1.86	1.60
Heat distortion, °F	D-648	540	540	530	565	565	560	545	570
Water absorption, %	D-570	0.28	0.27	0.27	0.27	0.26	0.30	0.20	0.22
Coefficient of friction dynamic–dry	Amoco Method	0.2-0.4	0.14	0.12	0.17	0.08	0.3-0.6	–	–
Hardness-Rockwell E	–	104	95	81	98	76	101	100	74
Dielectric constant, 10^5 cps	D-150	3.8	3.9	3.8	–	–	3.9	4.1	–
Dissipation factor, 10^5 cps	D-150	0.001	0.003	0.002	–	–	0.008	0.007	–

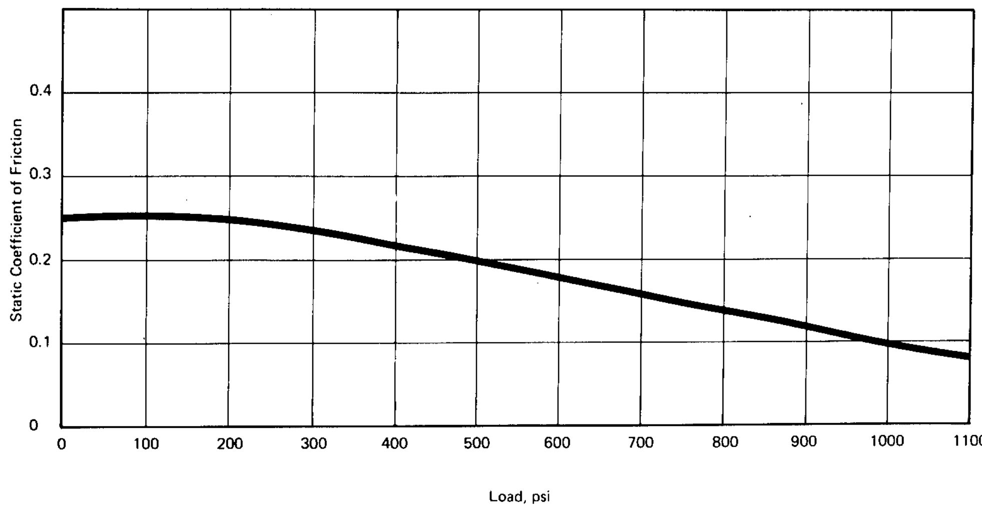

Fig. 2 - Static coefficient of friction as function of load for Meldin 8100. Conditions: sample configuration - 1/2 in diameter journal bushing; shaft - 8 μ in finish 1020 low carbon steel

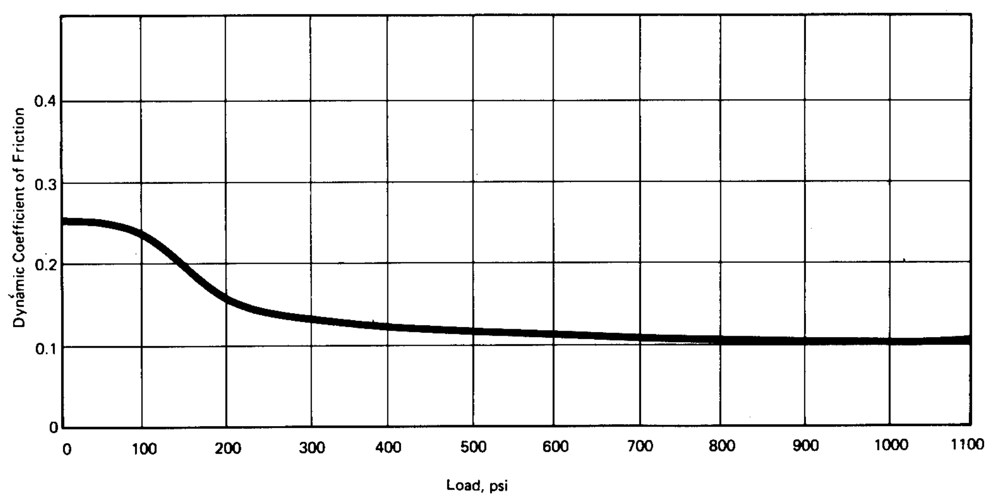

Fig. 3 - Dynamic coefficient of friction as function of load for Meldin 8100. Conditions: velocity - 50 ft/min; sample configuration - 1/2 in diameter journal bushing; shaft - 8 μ in finish 1020 low carbon steel

tion based on Torlon resins. The data in Figs. 2-4 were provided by Dixon Corp., Bristol, R.I., for their Torlon-based Meldin* 8100 series of bearings. For this blend, the effect of pressure on the coefficients of static and dynamic friction are shown in Figs. 2 and 3, respectively. Both sets of data were run on a 1/2 in diameter journal bearing test sample against a shaft of 1020 low carbon steel with an 8 μin finish. The coefficient of friction is comparable to many filled PTFE systems at room temperature and remains almost constant up to a temperature of approximately 500°F (260°C), at which time it decreases by about 40%. Bearings of Meldin 8100 are capable of sustained use at temperatures up to approximately 500°F (260°C).

*Dixon Corp. trademark.

The product of the pressure, P, exerted on a bearing and its velocity, V, has become a standard measure of the severity of bearing service. Although this measure is affected by other variables (for example, temperature, surface preparation, contaminants) and must be used with caution when comparing widely different pressures and velocities (for example, the same wear rate may not result from a high P-low V condition and a low P-high V condition, both of which result in the same PV product), the measure can be used for rough comparisons under moderate operating conditions.

A PV limit can also be defined, subject to the above cautions, which describes a critical change in a material's bearing performance as a result of the plastic matrix melting, unstable friction, thermal decomposition, or other breakdown mechanisms.

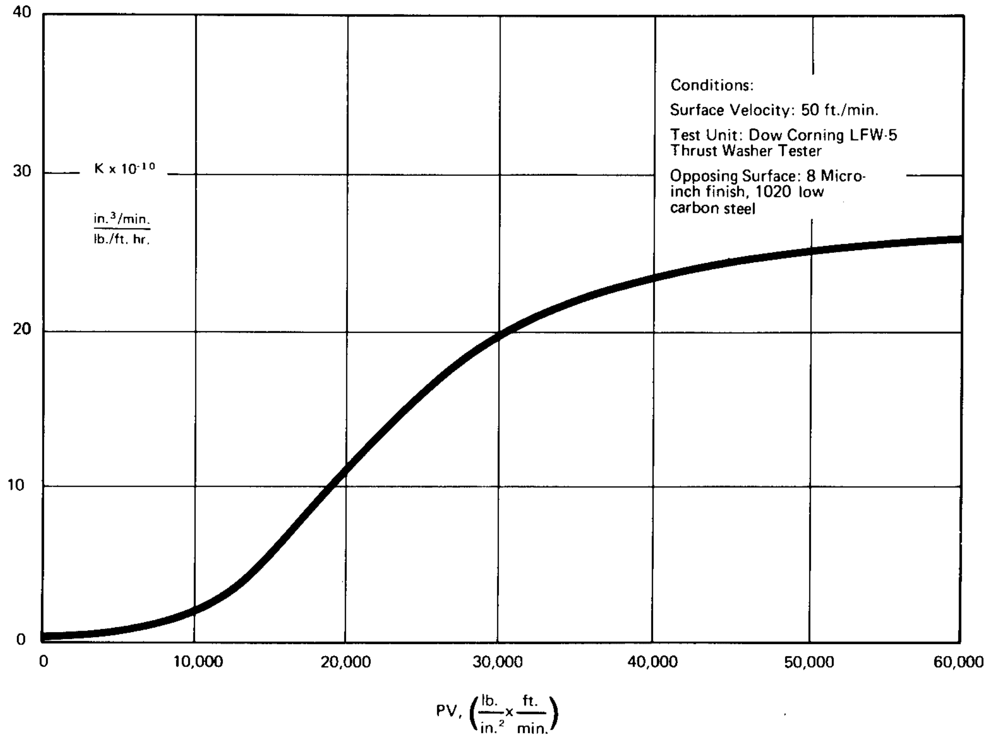

Fig. 4 - K factor as function of PV for Meldin 8100

The wear experienced by a bearing can be expressed as:

$$t = K\,PVT \quad (1)$$

where:

t = wear, in
P = pressure on bearing surface, psi
V = bearing surface velocity, ft/min
T = time, h
K = wear factor determined at given PV condition, $\frac{in^3/min}{lb/ft/h}$

The K factor is determined experimentally on a test apparatus as similar in configuration as possible to the intended application, and is then used to determine either the estimated wear or the bearing dimensions required to achieve a given wear rate.

Fig. 4 describes the wear factor, K, which has been measured on Meldin 8100 bearings using a Dow Corning LFW-5 thrust washer tester at a surface velocity of 50 ft/min against a 1020 low carbon steel (8 μin finish) test bed. Extremely low K factors are observed at PV values below 10,000 and moderate values are observed below 60,000 PV, the limit of the machine used for the test. It is estimated from this and other tests that the PV limit of Meldin 8100 at a velocity of 50 ft/min is approximately 100,000.

Although these data were developed on a compression moldable member of the Torlon family, several companies are at work developing formulations that can be extruded and injection molded. The results of these programs are promising, and extruded and injection molded bearings based on these new formulations should be appearing in the marketplace shortly.

SUMMARY

Poly(amide-imide) resins offer the design engineer a new tool for use on his more difficult problems, especially in the areas of heat resistance, friction, and wear.

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