SECTION 18 DESIGN OF PLASTIC GEARS

18.1 General Considerations Of Plastic Gearing

Plastic gears are continuing to displace metal gears in a widening arena of applications. Their unique characteristics are also being enhanced with new developments, both in materials and processing. In this regard, plastics contrast somewhat dramatically with metals, in that the latter materials and processes are essentially fully developed and, therefore, are in a relatively static state of development.

Plastic gears can be produced by hobbing or shaping, similarly to metal gears or alternatively by molding. The molding process lends itself to considerably more economical means of production; therefore, a more in-depth treatment of this process will be presented in this section.

Among the characteristics responsible for the large increase in plastic gear usage, the following are probably the most significant:

1. Cost effectiveness of the injection-molding process.
2. Elimination of machining operations; capability of fabrication with inserts and integral designs.
3. Low density: lightweight, low inertia.
4. Uniformity of parts.
5. Capability to absorb shock and vibration as a result of elastic compliance.
6. Ability to operate with minimum or no lubrication, due to inherent lubricity.
7. Relatively low coefficient of friction.
8. Corrosion-resistance; elimination of plating, or protective coatings.
9. Quietness of operation.
10. Tolerances often less critical than for metal gears, due in part to their greater resilience.
11. Consistency with trend to greater use of plastic housings and other components.
12. One step production; no preliminary or secondary operations.

At the same time, the design engineer should be familiar with the limitations of plastic gears relative to metal gears. The most significant of these are the following:

1. Less load-carrying capacity, due to lower maximum allowable stress; the greater compliance of plastic gears may also produce stress concentrations.
2. Plastic gears cannot generally be molded to the same accuracy as high-precision machined metal gears.
3. Plastic gears are subject to greater dimensional instabilities, due to their larger coefficient of thermal expansion and moisture absorption.
4. Reduced ability to operate at elevated temperatures; as an approximate figure, operation is limited to less than 120ºC. Also, limited cold temperature operations.
5. Initial high mold cost in developing correct tooth form and dimensions.
6. Can be negatively affected by certain chemicals and even some lubricants.
7. Improper molding tools and process can produce residual internal stresses at the tooth roots, resulting in over stressing and/or distortion with aging.
8. Costs of plastics track petrochemical pricing, and thus are more volatile and subject to increases in comparison to metals.

18.2 Properties Of Plastic Gear Materials

Popular materials for plastic gears are acetal resins such as DELRIN*, Duracon M90; nylon resins such as ZYTEL*, NYLATRON**, MC901 and acetal copolymers such as CELCON***. The physical and mechanical properties of these materials vary with regard to strength, rigidity, dimensional stability, lubrication requirements, moisture absorption, etc. Standardized tabular data is available from various manufacturers' catalogs. Manufacturers in the U.S.A. provide this information in units customarily used in the U.S.A. In general, the data is less simplified and fixed than for the metals. This is because plastics are subject to wider formulation variations and are often regarded as proprietary compounds and mixtures. **Tables 18-1** through **18-9** are representative listings of physical and mechanical properties of gear plastics taken from a variety of sources. All reprinted tables are in their original units of measure.

Table 18-1 Physical Properties of Plastics Used in Gears

Material	Tensile Strength (psi x 10^3)	Flexural Strength (psi x 10^3)	Compressive Modulus (psi x 10^3)	Heat Distortion Temperature (°F @ 264psi)	Water Absorption (% in 24 hrs)	Rockwell Hardness	Mold Shrinkage (in./in.)
Acetal	8.8 – 1.0	13 – 14	410	230 – 255	0.25	M94 R120	0.022
ABS	4.5 – 8.5	5 – 13.5	120 – 200	180 – 245	0.2 – 0.5	R80 – 120	0.003 0.007
Nylon 6/6	11.2 – 13.1	14.6	400	200	1.3	R118 – 123	0.007 0.015
Nylon 6/10	7 – 8.5	10.5	400	145	0.4	R111	0.015
Polycarbonate	8 – 9.5	11 – 13	350	265 – 290	0.15	M70 R112	0.005 0.007 0.003
High Impact Polystyrene	1.9 – 4	5.5 – 12.5	300 – 500	160 – 205	0.05 – 0.10	M25 – 69	0.005
Polyurethane	4.5 – 8	7.1	85	160 – 205	0.60 – 0.80	M29 R90	0.009
Polyvinyl Chloride	6 – 9	8 – 15	300 – 400	140 – 175	0.07 – 0.40	R100 – 120	0.002 0.004
Polysulfone	10.2	15.4	370	345	0.22	M69 R120	0.0076
MoS_2–Filled Nylon	10.2	10	350	140	0.4	D785	0.012

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*   Registered trademark, E.I. du Pont do Nemours and Co., Wilmington, Delaware, 19898.
** Registered trademark, The Polymer Corporation, P.O. Box 422, Reading, Pennsylvania, 19603.
***Registered trademark, Celanese Corporation, 26 Main St., Chatham, N.J. 07928.

Table 18-2 Property Chart for Basic Polymers for Gearing

	Water Absorp. 24hrs.	Mold Shrinkage	Tensile Strength * Yield •Break	Flexural Modulus	Izod Impact Strength Notched	Deflect. Temp. @264psi	Coeff. of Linear Thermal Expan.	Specific Gravity
Units	**%**	**in./in.**	**psi**	**psi**	**ft.lb/in.**	**ºF**	**10^{-5} ºF**	
ASTM	**D570**	**D955**	**D638**	**D790**	**D256**	**D648**	**D696**	**D792**
1. Nylon 6/6	1.5	.015/.030	*11,200	175,000	2.1	220	4.5 varies	1.13/1.15
2. Nylon 6	1.6	.013/.025	*11,800	395,000	1.1	150	4.6	1.13
3. Acetal	0.2	.016/.030	*10,000	410,000	1.4/2.3	255	5.8	1.42
4.Polycarbonate 30% G/F, 15%PTFE	0.06	.0035	*17,500	1,200,000	2	290	1.50	1.55
5. Polyester (thermoplastic)	0.08	.020	*8,000 •12,000	340,000	1.2	130	5.3	1.3
6.Polyphenylene sulfide 30% G/F 15%PTFE	0.03	.002	*19,000	1,300,000	1.10	500	1.50	1.69
7. Polyester elastomer	0.3	.012	*3,780 •5,500	-	-	122	10.00	1.25
8. Phenolic (molded)	0.45	.007	•7,000	340,000	.29	270	3.75	1.42

* These are average values for comparison purpose only.
Source: Clifford E. Adams, Plastic Gearing, Marcel Dekker Inc., N.Y. 1986. Reference 1.

Table 18-3 Physical Properties of DELRIN Acetal Resin and ZYTEL Nylon Resin

Properties-Units	ASTM	"DELRIN"		"ZYTEL" 101	
		500	**100**	**.2% Moisture**	**2.5% Moisture**
Yield Strength, psi	D638*	10,000		11,800	8,500
Shear Strength, psi	D732*	9,510		9,600	
Impact Strength (Izod)	D256*	1.4	2.3	0.9	2.0
Elongation at Yield,%	D638*	15	75	5	25
Modulus of Elasticity, psi	D790*	410,000		410,000	175,000
Hardness, Rockwell	D785*	M 94, R 120		M79 R118	M 94, R 120, etc.
Coefficient of Linear Thermal Expansion, in./in.ºF	D696	4.5×10^{-5}		4.5×10^{-5}	
Water Absorption					
24 hrs. %	D570	0.25		1.5	
Saturation, %	D570	0.9		8.0	
Specific Gravity	D792	1.425		1.14	1.14

* Test conducted at 73ºF
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Table 18-4 Properties of Nylatron GSM Nylon

Property	Units	ASTM No.	Value
Specific Gravity	–	D 792	1.15 - 1.17
Tensile Strength, 73°F	psi	D 638	11,000 - 14,000
Elongation, 73°F	%	D 638	10 - 60
Modulus of Elasticity, 73°F	psi	D 638	350,000 - 450,000
Compressive Strength	psi	D 695	
@ 0.1% Offset			9,000
@ 1.0% Offset			12,000
Shear Strength, 73°F	psi	D 732	10,500 - 11,500
Tensile Impact, 73°F	ft.lb./in.^{2}	–	80 - 130
Deformation Under Load 122°F, 2000psi	%	D 621	0.5 - 1.0

Property	Units	ASTM No.	Value
Hardness (Rockwell), 73°F	–	D-785	R112 - 120
Coefficient of Friction (Dry vs Steel) Dynamic	–	–	.15 - .35
Heat Distortion Temp.			
66 psi	°F	D-648	400 - 425
264psi	°F	D-648	200 - 425
Melting Point	°F	D-789	430 ±10
Flammability	–	D-635	Self-extinguishing
Coefficient of Linear Thermal Expansion	in./in.°F	D-696	5.0×10^{-5}
Water Absorption			
24 Hours	%	D-570	.6 - 1.2
Saturation	%	D-570	5.5 - 6.5

Resistant to: Common Solvents, Hydrocarbons, Esters, Ketones, Alkalis, Diluted Acids
Not Resistant to: Phenol, Formic Acid, Concentrated Mineral Acid
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Table 18-5 Typical Thermal Properties of "CELCON" Acetal Copolymer

Property	ASTM Test Method	Units	M Series	GC-25A
Flow, Softening and Use Temperature				
Flow Temperature	D 569	ºF	345	-
Melting Point	-	ºF	329	331
Vicat Softening Point	D1525	ºF	324	324
Unmolding Temperature[1]	-	ºF	320	-
Thermal Deflection and Deformation				
Deflection Temperature	D648			
@264 psi		ºF	230	322
@66 psi		ºF	316	
Deformation under Load (2000 psi @122ºF)	D621	%	1.0	0.6
Miscellaneous				
Thermal Conductivity	-	BTU/hr./ft²/Fº/in.	1.6	-
Specific Heat	-	BTU/lb./ºF	0.35	-
Coefficient of Linear Thermal Expansion (Range:- 30ºC to + 30ºC.)	D696	in./in.ºF		
Flow direction			4.7×10^{-5}	2.2×10^{-5}
Traverse direction			4.7×10^{-5}	4.7×10^{-5}
Flammability	D635	in./min.	1.1	-
Average Mold Shrinkage²	-	in./in.		
Flow direction			0.022	0.004
Transverse direction			0.018	0.018

[1]Unmolding temperature is the temperature at which a plastic part loses its structural integrity (under its own weight) after a half-hour exposure.
²Data Bulletin C3A, "Injection Molding Celcon," gives information of factors which influence mold shrinkage. Reprinted with the permission of Celanese Plastics and Specialties Co.; see Reference 3.

Table 18-6 Mechanical Properties of Nylon MC9O1 and Duracon M90

Properties	Testing Method ASTM	Unit	Nylon MC901	Duracon M90
Tensile Strength	D 638	kgf/cm²	800-980	620
Elongation	D638	%	10-50	60
Modules of Elasticity (Tensile)	D638	10^3kgf/cm²	30-35	28.8
Yield Point (Compression)	D638	kgf/cm²	940-1050	-
5% Deformation Point	D638	kgf/cm²	940-970	-
Modules of Elasticity (Compress)	D638	10^3kgf/cm²	33-36	-
Shearing Strength	D732	kgf/cm²	735-805	540
Rockwell Hardness	D785	R scale	115-120	980
Bending Strength	D790	kgf/cm²	980-1120	980
Density (23ºC)	D792	-	1.15-1.17	1.41
Poisson's Ratio	-	-	0.40	0.35

Table 18-7 Thermal Properties of Nylon MC9O1 and Duracon M90

Properties	Testing Method ASTM	Unit	Nylon MC901	Duracon M90
Thermal Conductivity	C177	10^{-1}Kcal/mhrºC	2	2
Coeff. of Linear Thermal Expansion	D696	10^{-5}cm/cm/ºC	9	9-13
Specifical Heat (20ºC)		cal/ºCgrf	90.4	0.35
Thermal Deformation Temperature (18.5 kgf/cm²)	D648	ºC	160-200	110
Thermal Deformation Temperature (4.6 kgf/cm²)	D648	ºC	200-215	158
Antithermal Temperature (Long Term)		ºC	120-150	-
Deformation Rate Under Load (140 kgf/cm², 50ºC)	D621	%	0.65	-
Melting Point		ºC	220-223	165

Table 18-8 Typical Physical/Mechanical Properties of CELCON® Acetal Copolymer

Property English Units (Metric Units)	ASTM Test Method	Nominal Specimen Size	Temp.	M-Series Values	GC-25A Values	Temp.	M-Series Values	GC-25A Values
Specific Gravity	D 792			1.41	1.59		1.41	1.59
Density lbs/in³ (g/cm³)				0.0507	0.057			
Specific Volume lbs/in³ (cm³/g)				19.7	17.54		0.71	0.63
Tensile Strength at Yield lbs/in² (kg/cm²)	D 638 Speed B	Type I 1/8"	–40 °F 73 °F 160 °F	13,700 8,800 5,000	16,000 (at break)	–40 °C 23 °C 70 °C	965 620 350	1120 (at break)
Elongation at Break %	D 638 Speed B	Type I 1/8" Thick	–40 °F 73 °F 160 °F	M25/30 M90/20 M270/15 M25/75 M90/60 M270/40 250	2 – 3	–40 °C 23 °C 70 °C	M25/30 M90/20 M270/15 M25/75 M90/60 M270/40 250	2 – 3
Tensile Modulus lbs/in² (kg/cm²)	D 638	Type I 1/8" Thick		410,000	1.2 x 10⁶		28,800	84,500
Flexural Modulus lbs/in² (kg/cm²)	D 790	5" x 1/2" x 1/8" Thick	73 °F 160 °F 220 °F	375,000 180,000 100,000	1.05x10⁶ 0.7x10⁶ 0.5x10⁶	23 °C 70 °C 105 °C	26,400 12,700 7,000	74,000 50,000 35,000
Flexural Stress at 5% Deformation lbs/in² (kg/cm²)	D 790	5" x 1/2" x 1/8" Thick		13,000			915	
Compressive Stress at 1% Deflection lbs/in² (kg/cm²) at 10% Deflection lbs/in² (kg/cm²)	D 695	1" x 1/2" x 1/2"		4,500 16,000			320 1,100	
Izod Impact Strength (Notched) ft–lb/in.notch (kg·cm/cm notch)	D 256	2 1/2" x 1/2" x 1/8" machined notch	–40 °F 73 °F	M25/1.2 M90/1.0 M270/0.8 M25/1.5 M90/1.3 M270/1.0	1.1	–40 °C 23 °C	M25/6.5 M90/5.5 M270/4.4 M25/8.0 M90/7.0 M270/5.5	6.0
Tensile Impact Strength ft–lb/in² (kg·cm/cm²)	D 1822	L– Specimen 1/8" Thick		M25/90 M90/70 M270/60	50		M25/190 M90/150 M270/130	110
Rockwell Hardness M Scale	D 785	2" x1/8" Disc		80			80	
Shear Strength lbs/in² (kg/cm²)	D 732	2"x1/8" Disc	73 °F 120 °F 160 °F	7,700 6,700 5,700	8,300	23 °C 50 °C 70 °C	540 470 400	584
Water Absorption 24 – hr. Immersion %	D 570	2" x 1/8" Disc		0.22	0.29		0.22	0.29
Equilibrium, 50% R.H. %				0.16			0.16	
Equilibrium, Immersion				0.80			0.80	
Taper Abrasion 1000 g Load CS–17 Wheel	D 1044	4" x 4"		14mg per 1000 cycles			14mg per 1000 cycles	
Coefficient of Dynamic Friction • against steel, brass and aluminum • against Celcon	D 1894	3" x 4"		0.15 0.35			0.15 0.35	

Many of the properties of thermoplastics are dependent upon processing conditions, and the test results presented are typical values only. These test results were obtained under standardized test conditions, and with the exception of specific gravity, should not be used as a basis for engineering design. Values were obtained from specimens injection molded in unpigmented material. In common with other thermoplastics, incorporation into Celcon of color pigments or additional U.V. stabilizers may affect some test results. Celcon GC25A test results are obtained from material predried for 3 hours at 240ºF (116ºC) beforemolding. All values generated at 50% r.h. & 73ºF(23ºC)unless indicated otherwise.

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Table 18-9 Water and Moisture Absorption Property of Nylon MC9O1 and Duracon M90

Conditions	Testing Method ASTM	Unit	Nylon MC901	Duracon M90
Rate of Water Absorption (at room temp. in water, 24 hrs.)	D 570	%	0.5 - 1.0	0.22
Saturation Absorption Value (in water)		%	5.5 - 7.0	0.80
Saturation Absorption Value (in air, room temp.)		%	2.5 - 3.5	0.16

It is common practice to use plastics in combination with different metals and materials other than plastics. Such is the case when gears have metal hubs, inserts, rims, spokes, etc. In these cases, one must be cognizant of the fact that plastics have an order of magnitude different coefficients of thermal expansion as well as density and modulus of elasticity. For this reason, **Table 18-10** is presented.

Other properties and features that enter into consideration for gearing are given in **Table 18-11** (Wear) and **Table 18-12** (Poisson's Ratio).

Table 18-10 Modulus of Elasticity, Coefficients of Thermal Expansion and Density of Materials

Material	Modulus of Elasticity (flexural) (lb/in.^{2})	Coefficient of Thermal Expansion (per °F)	Temperature Range of Coefficient (°F)	Density (lb/in^3)
Ferrous Metals				
Cast Irons:				
Malleable	25 to 28 x 10^6	6.6 x 10^{-6}	68 to 750	.265
Gray cast	9 to 23 x 10^6	6.0 x 10^{-6}	32 to 212	.260
Ductile	23 to 25 x 10^6	8.2 x 10^{-6}	68 to 750	.259
Steels:				
Cast Steel	29 to 30 x 10^6	8.2 x 10^{-6}	68 to 1000	.283
Plain carbon	29 to 30 x 10^6	8.3 x 10^{-6}	68 to 1000	.286
Low alloy,cast and wrought	30 x 10^6	8.0 x 10^{-6}	0 to 1000	.280
High alloy	30 x 10^6	8 to 9 x 10^{-6}	68 to 1000	.284
Nitriding , wrought	29 to 30 x 10^6	6.5 x 10^{-6}	32 to 900	.286
AISI 4140	29 x 10^6	6.2 x 10^{-6}	32 to 212	.284
Stainless:				
AISI 300 series	28 x 10^6	9.6 x 10^{-6}	32 to 212	.287
AISI 400 series	29 x 10^6	5.6 x 10^{-6}	32 to 212	.280
Nonferrous Metals:				
Aluminum alloys, wrought	10 to 10.6 x 10^6	12.6 x 10^{-6}	68 to 212	.098
Aluminum, sand–cast	10.5 x 10^6	11.9 to 12.7 x 10^{-6}	68 to 212	.097
Aluminum, die–cast	10.3 x 10^6	11.4 to 12.2 x 10^{-6}	68 to 212	.096
Beryllium copper	18 x 10^6	9.3 x 10^{-6}	68 to 212	.297
Brasses	16 to 17 x 10^6	11.2 x 10^{-6}	68 to 572	.306
Bronzes	17 to 18 x 10^6	9.8 x 10^{-6}	68 to 572	.317
Copper, wrought	17 x 10^6	9.8 x 10^{-6}	68 to 750	.323
Magnesium alloys, wrought	6.5 x 10^6	14.5 x 10^{-6}	68 to 212	.065
Magnesium, die–cast	6.5 x 10^6	14 x 10^{-6}	68 to 212	.065
Monel	26 x 10^6	7.8 x 10^{-6}	32 to 212	.319
Nickel and alloys	19 to 30 x 10^6	7.6 x 10^{-6}	68 to 212	.302
Nickel, low–expansion alloys	24 x 10^6	1.2 to 5 x 10^{-6}	–200 to 400	.292
Titanium, unalloyed	15 to 16 x 10^6	5.8 x 10^{-6}	68 to 1650	.163
Titanium alloys, wrought	13 to 17.5 x 10^6	5.0 to 7 x 10^{-6}	68 to 572	.166
Zinc, die–cast	2 to 5 x 10^6	5.2 x 10^{-6}	68 to 212	.24
Powder Metals:				
Iron (unalloyed)	12 to 25 x 10^6	—	—	.21 to .27
Iron–carbon	13 x 10^6	7 x 10^{-6}	68 to 750	.22
Iron–copper–carbon	13 to 15 x 10^6	7 x 10^{-6}	68 to 750	.22
AISI 4630	18 to 23 x 10^6	—	—	.25
Stainless steels:				
AISI 300 series	15 to 20 x 10^6	—	—	.24
AISI 400 series	14 to 20 x 10^6	—	—	.23
Brass	10 x 10^6	—	—	.26
Bronze	8 to 13 x 10^6	10 x 10^{-6}	68 to 750	.28
Nonmetallics:				
Acrylic	3.5 to 4.5 x 10^5	3.0 to 4 x 10^{-5}	0 to 100	.043
Delrin (acetal resin)	4.1 x 10^5	5.5 x 10^{-5}	85 to 220	.051
Fluorocarbon resin (TFE)	4.0 to 6.5 x 10^4	5.5 x 10^{-5}	–22 to 86	.078
Nylon	1.6 to 4.5 x 10^5	4.5 to 5.5 x 10^{-5}	–22 to 86	.041
Phenolic laminate:				
Paper base	1.1 to 1.8 x 10^5	0.9 to 1.4 x 10^{-5}	–22 to 86	.048
Cotton base	0.8 to 1.3 x 10^5	0.7 to 1.5 x 10^{-5}	–22 to 86	.048
Linen base	0.8 to 1.1 x 10^5	0.8 to 1.4 x 10^{-5}	–22 to 86	.049
Polystyrene (general purpose)	4.0 to 5 x 10^5	3.3 to 4.4 x 10^{-5}	–22 to 86	.038

Source: Michalec, G.W., *Precision Gearing*, Wiley 1966

Table 18-11 Wear Characteristics of Plastics

Material	Steel	Brass	Polyurethane	Polycarbonate	MoS_2-Filled Nylon	Nylon 6/10	Nylon 6/6	Polystyrene	ABS	Acetal
Acetal	F	P	G	F	G	G	G	F	F	G
ABS	P	P	G	G	G	G	G	P	F	
Polystyrene	P	P	F	F	G	F	F	F		
Nylon 6-6	E	F	E	F	E	G	G			
Nylon 6-10	E	F	E	F	E	G				
MoS_2-Filled Nylon	E	G	E	F	E					
Polycarbonate	G	F	G	G						
Polyurethane	E	F	G							
Brass	G	P								
Steel	F									

Key
E — Excellent
G — Good
F — Fair
P — Poor

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Table 18-12 Poisson's Ratio μ for Unfilled Thermoplastics

Polymer	μ
Acetal	0.35
Nylon 6/6	0.39
Modified PPO	0.38
Polycarbonate	0.36
Polystyrene	0.33
PVC	0.38
TFE (Tetrafluorethylene)	0.46
FEP (Fluorinated Ethylene Propylene)	0.48

Source: Clifford E. Adams, Plastic Gearing, Marcel Dekker Inc., New York 1986. Reference 1.

Moisture has a significant impact on plastic properties as can be seen in **Tables 18-1** thru **18-5**. Ranking of plastics is given in **Table 18-13**. In this table, rate refers to expansion from dry to full moist condition. Thus, a 0.20% rating means a dimensional increase of 0.002 mm/mm. Note that this is only a rough guide, as exact values depend upon factors of composition and processing, both the raw material and gear molding. For example, it can be seen that the various types and grades of nylon can range from 0.07% to 2.0%.

Table 18-13 Material Ranking by Water Absorption Rate

Material	Rate of Change %
Polytetrafluoroethylene	0.0
Polyethylene: medium density	< 0.01
high density	< 0.01
high molecular weight	< 0.01
low density	< 0.015
Polyphenylene sulfides (40% glass filled)	0.01
Polyester: thermosetting and alkyds	
low shrink	0.01 – 0.25
glass – preformed chopping roving	0.01 – 1.0
Polyester: linear aromatic	0.02
Polyphenylene sulfide: unfilled	0.02
Polyester: thermoplastic (18% glass)	0.02 – 0.07
Polyurethane: cast liquid methane	0.02 – 1.5
Polyester synthetic: fiber filled – alkyd	0.05 – 0.20
glass filled – alkyd	0.05 – 0.25
mineral filled – alkyd	0.05 – 0.50
glass–woven cloth	0.05 – 0.50
glass–premix, chopped	0.06 – 0.28
Nylon 12 (30% glass)	0.07
Polycarbonate (10–40% glass)	0.07 – 0.20
Styrene–acrylonitrile copolymer (20–33% glass filled)	0.08 – 0.22
Polyester thermoplastic:	0.09
thermoplastic PTMT (20% asbestos)	0.10
glass sheet molding	0.10 – 0.15
Polycarbonate <10%glass	0.12
Phenolic cast: mineral filled	0.12 – 0.36
Polyester alkyd: asbestos filled	0.14
Polycarbonate: unfilled	0.15 – 0.18
Polyester cast: rigid	0.15 – 0.60
Acetal: TFE	0.20
Nylon 6/12 (30–35% glass)	0.20
6/10 (30–35% glass)	0.20
Polyester alkyd vinyl ester thermoset	0.20
Styrene–acrylonitrile copolymer: unfilled	0.20 – 0.30
Polycarbonate ABS alloy	0.20 – 0.35
Phenolic cast: unfilled	0.20 – 0.40
Acetal copolymer	0.22
homopolymer	0.25
Nylon 12 (unmodified)	0.25
Acetal (20% glass)	0.25 – 0.29
Poly (ancide–imide)	0.28
Acetal (25% glass)	0.29
Nylon 11 (unmodified)	0.30
Polyester elastomer	0.30 – 0.60
Polyamide	0.32
Nylon: 6/12 (unmodified)	0.40
6/10 (unmodified)	0.40
Polyester-thermosetting and alkyds (cast flexible)	0.50 – 2.50
Nylon 6 (cast)	0.60 – 1.20
Polyurethane elastomer thermoplastic	0.70 – 0.90
Nylon 6/6: MoS_2	0.80 – 1.10
30 – 35% glass	0.90
unmodified	1.10 – 1.50
nucleated	1.10 – 1.50
Nylon 6 (30 – 35% glass)	1.30
unmodified	1.30 – 1.90
nucleated	1.30 – 1.90
Nylon 6/6 – 6 (copolymer)	1.50 – 1.20

Source: Clifford E. Adams, *Plastic Gearing*, Marcel Dekker, Inc., New York, 1986. Reference 1.

Table 18-14 lists safe stress values for a few basic plastics and the effect of glass fiber reinforcement.

It is important to stress the resistance to chemical corrosion of some plastic materials. These properties of some of materials used in the products presented in this catalog are further explored.

Nylon MC9O1

Nylon MC901 has almost the same level of antichemical corrosion property as Nylon resins. In general, it has a better antiorganic solvent property, but has a weaker antiacid property. The properties are as follows:

Table 18-14 Safe Stress

Plastic	Safe stress, psi	
	Unfilled	Glass-reinforced
ABS Resins	3000	6000
Acetal	5000	7000
Nylon	6000	12000
Polycarbonate	6000	9000
Polyester	3500	8000
Polyurethane	2500	

Source: Clifford E. Adams, *Plastic Gearing*, Marcel Dekker Inc.,New York 1986. Reference 1.

- For many nonorganic acids, even at low concentration at normal temperature, it should not be used without further tests.
- For nonorganic alkali at room temperature, it can be used to a certain level of concentration.
- For the solutions of nonorganic salts, we may apply them to a fairly high level of temperature and concentration.
- MC901 has better antiacid ability and stability in organic acids than in nonorganic acids, except for formic acid.
- MC901 is stable at room temperature in organic compounds of ester series and ketone series.
- It is also stable in mineral oil, vegetable oil and animal oil, at room temperature.

Duracon M90

This plastic has outstanding antiorganic properties. However, it has the disadvantage of having limited suitable adhesives. Its main properties are:

- Good resistance against nonorganic chemicals, but will be corroded by strong acids such as nitric, sulfuric and chloric acids.
- Household chemicals, such as synthetic detergents, have almost no effect on M90.
- M90 does not deteriorate even under long term operation in high temperature lubricating oil, except for some additives in high grade lubricants.
- With grease, M90 behaves the same as with oil lubricants. Gear designers interested in using this material should be aware of properties regarding individual chemicals. Plastic manufacturers' technical information manuals should be consulted prior to making gear design decisions.

18.3 Choice Of Pressure Angles And Modules

Pressure angles of 14.5º, 20º and 25º are used in plastic gears. The 20º pressure angle is usually preferred due to its stronger tooth shape and reduced undercutting compared to the 14.5º pressure angle system. The 25º pressure angle has the highest load-carrying ability, but is more sensitive to center distance variation and hence runs less quietly. The choice is dependent on the application.

The determination of the appropriate module or diametral pitch is a compromise between a number of different design requirements. A larger module is associated with larger and stronger teeth. For a given pitch diameter, however, this also means a smaller number of teeth with a correspondingly greater likelihood of undercut at very low number of teeth. Larger teeth are generally associated with more sliding than smaller teeth.

On the other side of the coin, smaller modules, which are associated with smaller teeth, tend to provide greater load sharing due to the compliance of plastic gears. However, a limiting condition would eventually be reached when mechanical interference occurs as a result of too much compliance. Smaller teeth are also more sensitive to tooth errors and may be more highly stressed.

A good procedure is probably to size the pinion first, since it is the more highly loaded member. It should be proportioned to support the required loads, but should not be overdesigned.