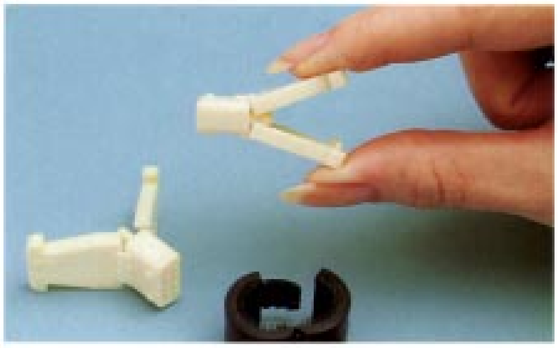
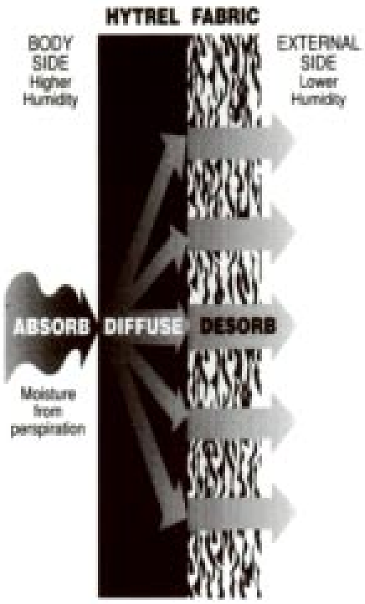
Hytrel®

engineering thermoplastic elastomer



Hytrel permits a new degree of freedom in designing tough, resilient, shock- and noise-isolating connectors and fasteners with integral hinges, springs, and seals.

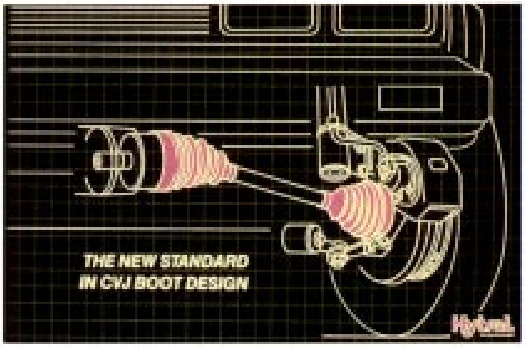
Miner Elastomer's TecsPak® devices are used in a variety of energy management applications. Such devices can undergo severe deformation repeatedly without deterioration in properties, like energy absorption, reliability, and durability.



Comfort. *Efficient evaporation of perspiration helps prevent heat stress. The grade of Hytrel used diffuses moisture faster than it can be exuded by the skin.*

Good feel. *The flexibility and conformability of Hytrel permits coated or laminated structures with excellent drape and hand.*

Splash and particulate protection. *The protective layer of Hytrel is monolithic (i.e., not microporous), and it resists attack by a wide range of chemicals. Proprietary electronic seaming technology prevents the entry of particulate dust, affording better protection than sewn garments.*



Benefits of a drive axle boot design in Hytrel over the previously used rubber part include:

- *Provides threefold increase in part life on the vehicle*
- *Superior resistance to mechanical damage*
- *One half the weight of the previous rubber part*
- *90% reduction in molding cycle time*

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Chapter 1

General Information

Contents

Description

Hytrel is the DuPont registered trademark for its engineering thermoplastic elastomers. The polyether-ester block copolymers combine many of the most desirable characteristics of high-performance elastomers and flexible plastics. Hytrel offers a unique combination of mechanical, physical, and chemical properties that qualifies it for demanding applications. The various grades of Hytrel exhibit a wide range of flexibility/stiffness and processing capabilities.

This brochure is intended to assist design engineers in the successful and efficient design of parts of Hytrel engineering thermoplastic elastomers. Many of the same design considerations that apply to metals and other engineering materials of construction apply to Hytrel. It is common practice to use standard engineering equations for designing with Hytrel. However, because all engineering materials are affected to some extent by temperature, moisture, and other environmental service conditions, it is necessary to determine the extreme operating conditions and to design a part so that it will perform satisfactorily under all these conditions.

The selection of the best material for any application requires a knowledge of the properties of all candidate materials and how they satisfy the requirements of the application. Hytrel may be chosen for a job because of one, or a combination, of its properties.

Much of the engineering data needed to design with Hytrel is given in the following pages and should be helpful to the designer. However, it is always important to test prototypes of a proposed design and material under realistic conditions before making production commitments.

Properties and Characteristics

Hytrel is an engineering thermoplastic elastomer that combines many of the most desirable characteristics of high-performance elastomers and flexible plastics. It features exceptional toughness and resilience; high resistance to creep, impact, and flex fatigue; flexibility at low temperatures; and good retention of properties at elevated temperatures. In addition, it resists deterioration from many industrial chemicals, oils, and solvents.

Processing

Hytrel can be readily formed into high-performance products by a variety of thermoplastic processing techniques, including injection molding, extrusion, blow molding, rotational molding, and melt casting. Hytrel is processed at temperatures between 177 and 260°C (350 and 500°F), depending on the process and polymer type. All standard grades have a sharp melting point and very good melt stability.

Applications

The excellent properties of Hytrel qualify it for a number of demanding applications where mechanical strength and durability are required in a flexible component. Examples include seals, belts, bushings, pump diaphragms, gears, protective boots, hose and tubing, springs, and impact-absorbing devices. In many of these applications, Hytrel allows a multipiece rubber, plastic, or even metal composite assembly to be replaced with a single part. For outdoor applications, Hytrel should be protected from ultraviolet (UV) attack.

Some of the industries where Hytrel can already be found include: automotive, fluid power, electrical/electronic, appliance and power tool, sporting goods, footwear, wire and cable (including fiber optics), furniture, and off-road transportation equipment. The potential for using Hytrel in other industries is limited only by one’s imagination.

Table 1
Compositions of Hytrel

High-Productivity Hytrel Resins These grades offer the best balance of properties and cost.			
Grade	**Description**	**Characteristics***	**Typical Uses**
Hytrel G3548W	Low modulus molding and extrusion grade. Contains improved color-stable antioxidants.	Very flexible grade of Hytrel. Excellent flex resistance, especially at low temperatures. Moldable even in thin sections. Can be used in light-colored products.	Applications requiring flex life coupled with good flexibility at low temperatures. Thin, flexible membranes. Good for high original color retention.
Hytrel G4074	Low modulus molding and extrusion grade. Contains a discoloring antioxidant.	Excellent heat-aging resistance and resistance to oils at high temperatures. Best low modulus molding and extrusion grade.	Tubing Hose jackets Wire and cable jackets Film sheeting Molded products
Hytrel G4078W	Low modulus molding and extrusion grade. Contains improved color-stable antioxidants.	Like Hytrel G4074, except that heat-aging resistance is reduced. Can be used in light-colored products.	Applications requiring high original color retention. Molded and extruded products for consumer use.
Hytrel G4774	Medium-low modulus molding and extrusion grade. Contains a discoloring antioxidant.	Excellent heat-aging resistance and resistance to oils at high temperatures. Good resistance to oils, fuels, and solvents.	Tubing Hose jackets Wire and cable jackets Profiles Molded products
Hytrel G4778	Medium-low modulus molding and extrusion grade. Contains color-stable antioxidants.	Good balance of low and high temperature properties.	Tubing Molded and extruded products for consumer use.
Hytrel G5544	Medium modulus molding and extrusion grade. Contains a discoloring antioxidant.	Excellent heat-aging resistance and resistance to oils at high temperatures.	Same as Hytrel G4774.

(continued)

* The characteristics shown are those of the unmodified standard composition. Special stabilizers and additives can be mixed with Hytrel to improve its resistance to UV light, heat aging, and moisture.

Table 1
Compositions of Hytrel *(continued)*

High-Performance Hytrel Resins

These grades provide an extra measure of strength or serviceability in the most demanding applications and can be used in light-colored products.

Grade	Description	Characteristics*	Typical Uses
Hytrel 4056	Low modulus extrusion grade. Contains color-stable antioxidants.	Excellent low-temperature properties. Excellent flex-fatigue resistance. Excellent creep resistance.	Hose jackets Wire and cable jackets Film and sheeting Belting Seals
Hytrel 4069	Low modulus molding and extrusion grade. Contains color-stable antioxidants.	Low modulus grade similar to Hytrel 4056 with a higher melting point.	Same as Hytrel 4056 and molded products.
Hytrel 4556	Medium-low modulus molding and extrusion grade. Contains color-stable antioxidants.	Same as Hytrel 4069.	Same as Hytrel 4056 and molded products.
Hytrel 5526	Medium modulus molding grade. Contains color-stable antioxidants.	Combine the best balance of properties of the product line.	Seals, packing, and gaskets Gears and bearings
Hytrel 5556	Medium modulus extrusion grade. Contains color-stable antioxidants.		Tubing and hose Wire and cable jackets Film and sheeting Belting
Hytrel 6356	Medium-high modulus molding and extrusion grade. Contains color-stable antioxidants.	Very good resistance to oils, hydraulic fluids, and fuels. Very good resistance to permeation by gases and liquids.	Tubing and hose Film Profiles Seals Gears and sprockets Fuel tanks
Hytrel 7246	High modulus molding and extrusion grade. Contains color-stable antioxidants.	High service temperature. Retains good low-temperature flexibility. Excellent resistance to oils, fuels, and solvents. Low fuel permeability.	Tubing Wire and cable jackets Gears and sprockets Oil field parts
Hytrel 8238	Highest modulus molding and extrusion grade. Contains color-stable antioxidants.	Highest service temperature. Best resistance to oils, fuels, and solvents. Lowest fuel permeability.	Tubing Wire and cable jackets Gears and sprockets Oil field parts Electrical connectors

(continued)

* The characteristics shown are those of the unmodified standard composition. Special stabilizers and additives can be mixed with Hytrel to improve its resistance to UV light, heat aging, and moisture.

Table 1
Compositions of Hytrel *(continued)*

Specialty Hytrel Resins			
Grade	**Description**	**Characteristics***	**Typical Uses**
Hytrel 3078	Very low modulus molding and extrusion grade. Contains color-stable antioxidants.	Most flexible grade of Hytrel with good strength and toughness over a wide temperature range.	Applications requiring flex life coupled with good flexibility at low temperatures. Thin, flexible membranes.
HTR4275BK	Pigmented black. Particularly suitable for extrusion blow molding and extrusion.	Good balance of properties combined with high viscosity for extrusion and blow molding applications.	Hollow thin-walled parts Blow film and sheeting Large diameter tubing Hose mandrels Profiles Automotive boots and covers
Hytrel 5555HS	Heat-stabilized grade of Hytrel 5556. Contains a discoloring antioxidant.	Combine the best balance of properties of the product line.	Tubing and hose Wire and cable jackets Film and sheeting Belting Used where increased heat-aging stability is required.
HTR5612BK	Pigmented black. Particularly suitable for extrusion blow molding and extrusion.	Good balance of properties combined with high viscosity for extrusion and blow molding applications.	Hollow thin-walled parts Blow film and sheeting Large diameter tubing Hose mandrels Profiles Automotive boots and covers
HTR6108	Medium-low modulus grade. Contains color-stable antioxidants.	Low permeability to oils, fuels, and plasticizers—approximately one-third that of other grades of similar stiffness. High clarity in thin films.	Applications requiring good flexibility coupled with low permeability to fuels, oils, and plasticizers. Coextrudable barrier membrane over more permeable substrates.
HTR8068	Medium-low modulus molding and extrusion grade. Flame retarded antidrip compound.	Meets requirements of UL-94 class V-0 at 1.57 mm (1/16 in) thickness.	Tubing and hose Wire and cable jackets Film and sheeting
HTR8139LV	Medium modulus, high viscosity grade, pigmented black. Particularly suitable for extrusion and extrusion blow molding.	Excellent flex fatigue resistance and excellent performance at low temperature. Formulated for improved surface lubricity.	Hollow thin-walled parts Blow film and sheeting Large diameter tubing Profiles Automotive boots and covers
HTR8171	Low modulus grade. Color-stable antioxidants.	Very high moisture vapor transmission rate for breathable film applications.	Breathable hospital gowns, clothing, medical films for wound care.
HTR8206	Medium-low modulus grade. Color-stable antioxidants.		

* The characteristics shown are those of the unmodified standard composition. Special stabilizers and additives can be mixed with Hytrel to improve its resistance to UV light, heat aging, and moisture.

Table 2
Typical Properties of Hytrel
(SI Units)

	Property[a]	Test Methods[b] ASTM	Test Methods[b] ISO	Unit	High-Productivity Grades[c] G3548W	G4074	G4078W	G4774	G4778	G5544	High-Performance Grades[c] 4056	4069
STIFFNESS	Hardness, durometer D	D 2240	868		35	40	40	47	47	55	40	40
	Flexural Modulus[d]	D 790 Method I Procedure B	178									
	at −40°C			MPa	62	207	166	320	320	850	155	172
	23°C			MPa	32.4	65.5	65.5	117	117	193	62	55
	100°C			MPa	7	33	16	69	69	125	27	28
STRESS/STRAIN	Tensile Stress at Break[e]	D 638	R527	MPa	10.3	13.8	17	20.7	20.7	31	28	27.6
	Elongation at Break[e]	D 638	R527	%	200	230	310	275	300	375	550	600
	Tensile Stress at 5% Strain[e]	D 638	R527	MPa	1.7	2.4	3.0	3.8	5.0	6.0	2.4	2.4
	Tensile Stress at 10% Strain[e]	D 638	R527	MPa	2.6	3.8	4.5	6.0	7.0	10.5	3.6	3.5
TOUGHNESS	Izod Impact (notched)[f]	D 256 Method A	R180									
	at −40°C			J/m	No Break	27	27	144	165	133	No Break	No Break
	23°C			J/m	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break
	Resistance to Flex Cut Growth, Ross (pierced)	D 1052	—	cycles to 5x cut growth	>1 x 10^6	>1 x 10^6	>1 x 10^6	>1 x 10^6	>1 x 10^6	8 x 10^5	>1 x 10^6	>1 x 10^6
	Initial Tear Resistance,[g] Die C	D 1004	34	kN/m	51	81	88	94	91	123	101	95
THERMAL	Melt Flow Rate	D 1238	1133	g/10 min	10	5.2	5.3	11	13	10	5.3	8.5
	Test Conditions: Temperature, °C at 2.16 kg load				190	190	190	230	230	230	190	220
	Melting Point[h]	D 3418	3146	°C	156	170	170	208	208	215	150	193
	Vicat Softening Point	D 1525 Rate B	306	°C	77	120	119	174	175	196	108	134
	Deflection Temperature under Flexural Load	D 648	75									
	at 0.5 MPa			°C	N/A	50	50	72	80	111	54	55
	at 1.8 MPa			°C	N/A	N/A	N/A	45	46	51	N/A	N/A
MISCELLANEOUS	Specific Gravity	D 792	R1183	—	1.15	1.18	1.18	1.20	1.20	1.22	1.17	1.11
	Water Absorption, 24 hr	D 570	62	%	5	2.1	3	2.5	2.3	1.5	0.6	0.7
	Abrasion Resistance at 1 kg load	D 1044 (Modified)	—	mg/1000 rev								
	Taber, CS-17 Wheel				30	9	20	13	12	9	3	15
	Taber, H-18 Wheel				310	193	260	168	162	116	100	80

[a] All properties were measured on injection-molded specimens at 23°C (73°F) unless specified otherwise. The values shown are for unmodified grades. Colorants or additives of any kind may alter some or all of these properties. The data listed here fall within the normal range of product properties, but they should not be used to establish specification limits or used alone as the basis of design.

[b] All of the values reported in this table are based on ASTM methods. ISO methods may produce different test results due to differences in test specimen dimensions and/or test procedures.

[c] The High-Productivity and High-Performance grades of Hytrel are named according to the following product key: first two digits: Hardness durometer D (in general, the greater the hardness, the stiffer the polymer); third digit: A measure of inherent viscosity; fourth digit: Type of antioxidant: 0–5 Discoloring, 6–9 Non-discoloring; Letter suffix: Special functions or colors.

[d] Crosshead speed 12.5 mm/min (0.5 in/min).

[e] ASTM Type IV dumbbells diecut from injection molded slab 2 mm (0.079 in) thick. Head speed 50 mm/min (2 in/min).

[f] Specimens 6.35 mm (0.25 in) thick.

[g] Specimens 2 mm (0.079 in) thick.

[h] Differential Scanning Calorimeter (DSC), peak of endotherm.

[i] Hardness, Rockwell R.

High-Performance Grades[c]						Specialty Grades								
4556	**5526**	**5556**	**6356**	**7246**	**8238**	**3078**	**HTR4275BK**	**5555HS**	**HTR5612BK**	**HTR6108**	**HTR8068**	**HTR8139LV**	**HTR8171**	**HTR8206**
45	55	55	63	72	82 (104)[i]	30	55	55	50	60	46	46	32	45
230	760	760	1,800	2,410	3,030	145	910	760	510	2,010	650	220	40	160
94	207	207	330	570	1,210	28	160	207	124	193	174	95	24.8	80
44	110	110	150	207	255	14	59	110	46	60	50	45	10.3	48
31	40	40	41	45.8	48.3	26.2	40	40	36	38.6	12.4	34	10.2	19.2
600	500	500	420	360	350	700	450	500	530	400	340	600	210	510
4.1	6.9	6.9	12	14	27.6	1.3	7.6	6.9	5.5	7.6	3.9	4.5	1.8	3.7
5.7	10.3	10.3	16	20	30.3	2.1	10.3	10.3	8.3	9.6	5.2	6.3	2.8	5.1
No Break	128	170	48	40	30	No Break	70	43	110	20	90	No Break	No Break	180
No Break	No Break	No Break	No Break	210	40	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break
$>1 \times 10^6$	5×10^5	5×10^5	5×10^5	3×10^4	N/A	$>1 \times 10^6$	5×10^4	1×10^5	6×10^5	6×10^5	—	$>1 \times 10^6$	$>1 \times 10^6$	—
116	158	158	175	200	253	77	163	158	145	150	75	123	45	86
8.5	18	7.5	8.5	12.5	12.5	5.0	1.8	8.5	3.0	5.2	4.6	3.3	9.0	12
220	220	220	230	240	240	190	230	220	230	190	190	230	190	230
193	203	203	211	218	223	170	196	203	196	168	169	192	150	200
158	180	180	195	207	212	83	174	180	155	148	110	161	76	151
60	90	90	115	130	140	46	68	90	62	50	—	68	42	62
43	49	49	51	52	55	N/A	45	49	44	42	—	46	N/A	38
1.14	1.20	1.20	1.22	1.25	1.28	1.07	1.16	1.20	1.16	1.24	1.43	1.15	1.17	1.19
0.6	0.5	0.5	0.3	0.3	0.3	3	0.5	0.7	0.4	0.2	1.9	0.7	54	30
3	7	6	7	13	9	2	20	—	38	9	25	4	85	0
72	70	64	77	47	20	90	227	112	186	116	—	65	240	65

Table 2
Typical Properties of Hytrel
(English Units)

	Property[a]	Test Methods[b]		Unit	High-Productivity Grades[c]						High-Performance Grades[c]	
		ASTM	ISO		G3548W	G4074	G4078W	G4774	G4778	G5544	4056	4069
STIFFNESS	Hardness, durometer D	D 2240	868		35	40	40	47	47	55	40	40
	Flexural Modulus[d]	D 790	178									
	at –40°F	Method I		psi	9,000	30,000	24,000	47,000	47,000	123,000	22,500	25,000
	73°F	Procedure B		psi	4,700	9,500	9,500	17,000	17,000	28,000	9,000	8,000
	212°F			psi	1,010	4,750	2,320	10,000	10,000	18,000	3,900	4,060
STRESS/STRAIN	Tensile Stress at Break[e]	D 638	R527	psi	1,490	2,000	2,460	3,000	3,000	4,500	4,050	4,000
	Elongation at Break[e]	D 638	R527	%	200	230	310	275	300	375	550	600
	Tensile Stress at 5% Strain[e]	D 638	R527	psi	240	350	440	550	670	875	350	350
	Tensile Stress at 10% Strain[e]	D 638	R527	psi	380	550	650	875	980	1,520	525	510
TOUGHNESS	Izod Impact (notched)[f]	D 256	R180									
	at –40°F	Method A		ft·lbf/in	No Break	0.5	0.5	2.7	3.1	2.5	No Break	No Break
	73°F			ft·lbf/in	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break
	Resistance to Flex Cut Growth, Ross (pierced)	D 1052	—	cycles to 5x cut growth	>1 x 10^6	>1 x 10^6	>1 x 10^6	>1 x 10^6	>1 x 10^6	8 x 10^5	>1 x 10^6	>1 x 10^6
	Initial Tear Resistance,[g] Die C	D 1004	34	lbf/in	290	460	500	535	520	700	580	550
THERMAL	Melt Flow Rate	D 1238	1133	g/10 min	10	5.2	5.3	11	13	10	5.3	8.5
	Test Conditions: Temperature, °F											
	at 2.16 kg load				374	374	374	446	446	446	374	428
	Melting Point[h]	D 3418	3146	°F	312	338	338	406	406	419	302	379
	Vicat Softening Point	D 1525 Rate B	306	°F	171	248	246	345	347	385	226	273
	Deflection Temperature under Flexural Load	D 648	75									
	at 66 psi			°F	N/A	122	122	162	176	232	129	131
	at 264 psi			°F	N/A	N/A	N/A	113	115	124	N/A	N/A
MISCELLANEOUS	Specific Gravity	D 792	R1183	—	1.15	1.18	1.18	1.20	1.20	1.22	1.17	1.11
	Water Absorption, 24 hr	D 570	62	%	5	2.1	3	2.5	2.3	1.5	0.6	0.7
	Abrasion Resistance at 1 kg load	D 1044 (Modified)	—	mg/1000 rev								
	Taber, CS-17 Wheel				30	9	20	13	12	9	3	15
	Taber, H-18 Wheel				310	193	260	168	162	116	100	80

[a] All properties were measured on injection-molded specimens at 73°F (23°C) unless specified otherwise. The values shown are for unmodified grades. Colorants or additives of any kind may alter some or all of these properties. The data listed here fall within the normal range of product properties, but they should not be used to establish specification limits or used alone as the basis of design.

[b] All of the values reported in this table are based on ASTM methods. ISO methods may produce different test results due to differences in test specimen dimensions and/or test procedures.

[c] The High-Productivity and High-Performance grades of Hytrel are named according to the following product key: first two digits: Hardness durometer D (in general, the greater the hardness, the stiffer the polymer); third digit: A measure of inherent viscosity; fourth digit: Type of antioxidant: 0–5 Discoloring, 6–9 Non-discoloring; Letter suffix: Special functions or colors.

[d] Crosshead speed 0.5 in/min (12.5 mm/min).

[e] ASTM Type IV dumbbells diecut from injection molded slab 0.079 in (2 mm) thick. Head speed 2 in/min (50 mm/min).

[f] Specimens 0.25 in (6.35 mm) thick.

[g] Specimens 0.079 in (2 mm) thick.

[h] Differential Scanning Calorimeter (DSC), peak of endotherm.

[i] Hardness, Rockwell R.

High-Performance Grades[c]						Specialty Grades								
4556	**5526**	**5556**	**6356**	**7246**	**8238**	**3078**	**HTR4275BK**	**5555HS**	**HTR5612BK**	**HTR6108**	**HTR8068**	**HTR8139LV**	**HTR8171**	**HTR8206**
45	55	55	63	72	82 (104)[i]	30	55	55	50	60	46	46	32	45
33,000	110,000	110,000	260,000	350,000	440,000	21,000	132,000	110,000	74,000	292,000	93,700	31,900	5,800	23,200
14,000	30,000	30,000	48,000	83,000	175,000	4,000	23,200	30,000	18,000	28,000	25,200	13,780	3,600	11,600
6,400	16,000	16,000	22,000	30,000	37,000	2,030	8,550	16,000	6,700	8,700	7,300	6,530	1,490	7,000
4,500	5,800	5,800	5,950	6,650	7,000	3,800	5,800	5,800	5,230	5,600	1,800	4,930	1,480	2,780
600	500	500	420	360	350	700	450	500	530	400	340	600	210	510
600	1,000	1,000	1,740	2,030	4,000	190	1,100	1,000	800	1,100	570	650	260	540
830	1,500	1,500	2,320	2,900	4,400	300	1,500	1,500	1,200	1,400	750	910	410	740
No Break	2.4	3.2	0.9	0.8	0.5	No Break	1.4	0.8	2.1	0.4	1.7	No Break	No Break	3.3
No Break	No Break	No Break	No Break	3.9	0.8	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break
$>1 \times 10^6$	5×10^5	5×10^5	5×10^5	3×10^4	N/A	1×10^6	5×10^4	1×10^5	6×10^5	6×10^5	—	$>1 \times 10^6$	$>1 \times 10^6$	—
660	900	900	1,000	1,150	1,440	440	930	900	830	855	430	700	260	490
8.5	18	7.5	8.5	12.5	12.5	5.0	1.8	8.5	3.0	5.2	4.6	3.3	9.0	12
428	428	428	446	464	464	374	446	428	446	374	374	446	374	446
379	397	397	412	424	433	338	385	397	385	334	336	378	302	392
316	356	356	383	405	414	181	345	356	311	298	230	322	169	304
140	194	194	239	266	284	115	154	194	144	122	—	154	108	144
110	120	120	124	126	131	N/A	113	120	111	108	—	115	N/A	100
1.14	1.20	1.20	1.22	1.25	1.28	1.07	1.16	1.20	1.16	1.24	1.43	1.15	1.17	1.19
0.6	0.5	0.5	0.3	0.3	0.3	3	0.5	0.7	0.4	0.2	1.9	0.7	54	30
3	7	6	7	13	9	2	20	—	38	9	25	4	85	0
72	70	64	77	47	20	90	227	112	186	116	—	65	240	65

Chapter 2

Mechanical Properties

Contents

Tensile Properties (ASTM D 638)

Tensile elongation and tensile modulus measurements are among the most important indications of strength in a material and are the most widely specified properties of plastic materials. The tensile test is a measurement of the ability of a material to withstand forces that tend to pull it apart and to determine to what extent the material stretches before breaking. The tensile modulus of elasticity is an indication of the relative stiffness of a material and can be determined from a stress-strain diagram. Different types of materials are often compared on the basis of tensile strength, elongation, and tensile modulus.

Tensile Stress-Strain

A stress-strain curve shows the relationship of an increasing force on a test sample to the resulting elongation of the sample. Some of the factors that affect the curve are: temperature, type of resin, rate of testing, etc.

Tensile properties over a range of temperatures are shown in **Figures 1–10**. Because of the elastomeric nature of Hytrel, elongation before break is high; as a result, low-strain-level and high-strain-level curves are presented separately to facilitate selection of strain levels.

Tensile Strength

The tensile strength values are obtained from stress-strain curves by noting the maximum stress on the curve. The maximum tensile values are given in **Table 2** and can be used in rating the relative resin strengths.

Generally, the stiffer grades of Hytrel show higher tensile strengths and shorter elongations than the softer grades. The stiffer grades are higher in the crystalline polyester hard segment and therefore behave more like typical engineering plastics.

Yield Strength

The yield strength, also taken from the stress-strain curve, is the point at which the material continues to elongate (strain) without additional stress. The yield strength often has a lower value than the tensile strength. For Hytrel, the maximum stress is usually at the breaking point; however, for some of the harder grades at low temperatures, the maximum stress may be at the yield point. The more flexible grades of Hytrel behave more like elastomeric materials. They do not show any yield under the conditions used in the tests.

In the design of plastic parts, yield strength is the most common reference, as it is uncommon for a part to be stressed beyond the yield point. Unless one is designing gaskets and washers, which are often stressed beyond the yield point, it is good practice to design within the proportional limit, which is substantially below the yield point.

Figure 1. Tensile Properties—Hytrel G4074

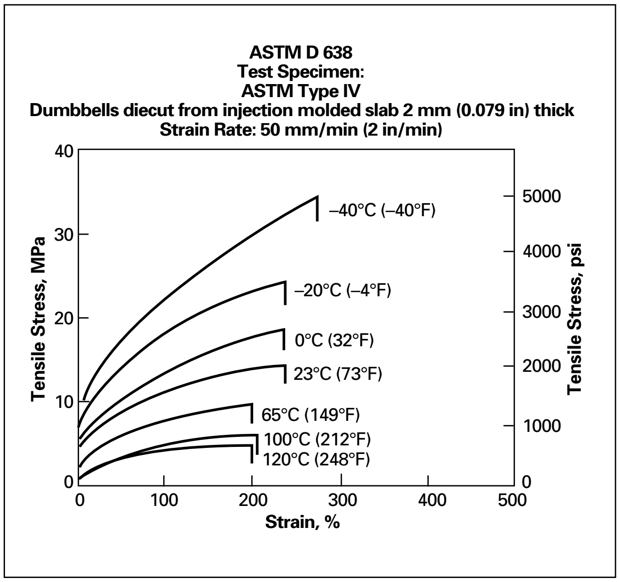


Figure 2. Tensile Stress at Low Strain—Hytrel G4074

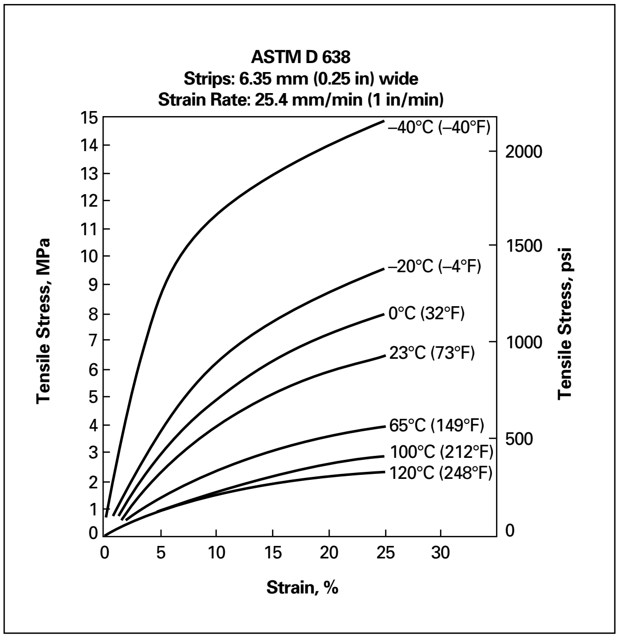


Figure 3. Tensile Properties—Hytrel 4056

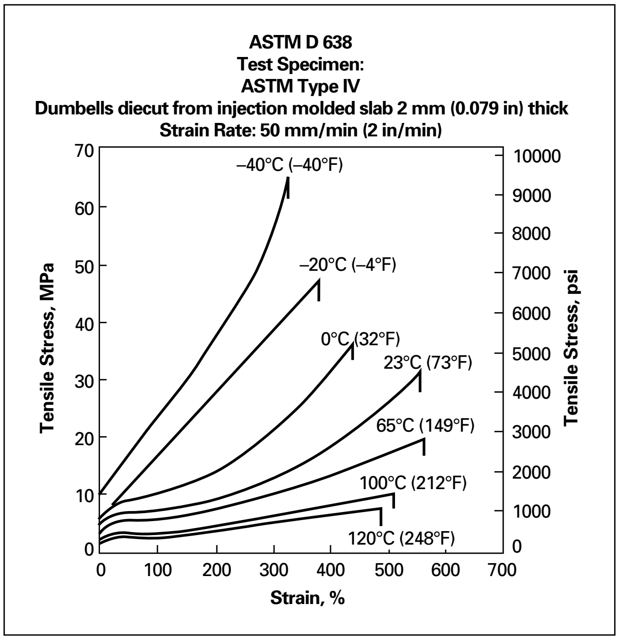


Figure 4. Tensile Stress at Low Strain—Hytrel 4056

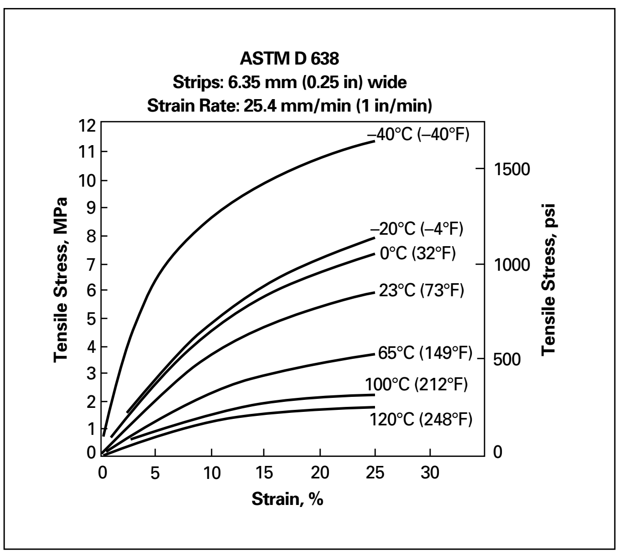


Figure 5. Tensile Properties—Hytrel 5526/5556

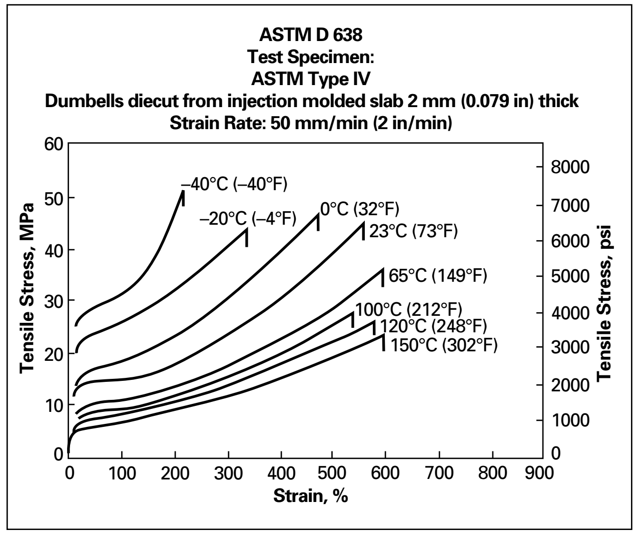


Figure 6. Tensile Stress at Low Strain—Hytrel 5526/5556

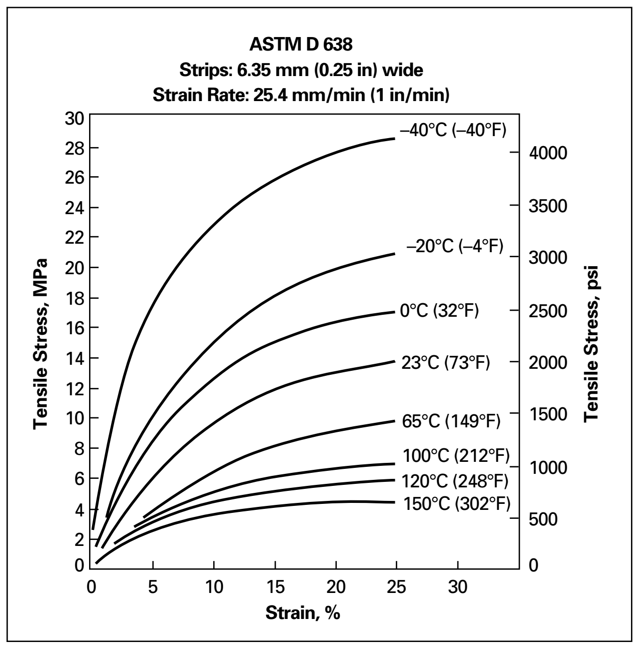


Figure 7. Tensile Properties—Hytrel 6356

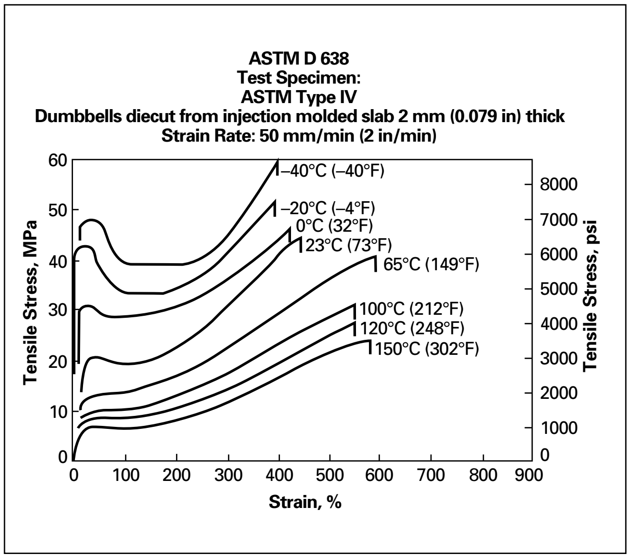


Figure 8. Tensile Stress at Low Strain—Hytrel 6356

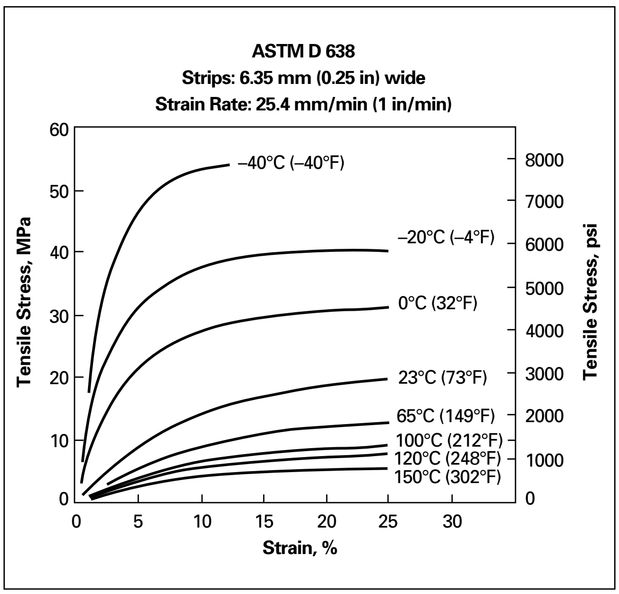


Figure 9. Tensile Properties—Hytrel 7246

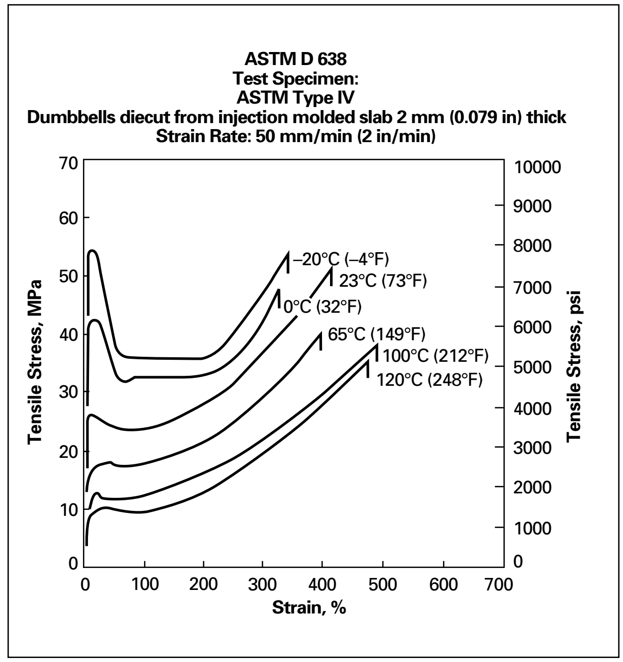
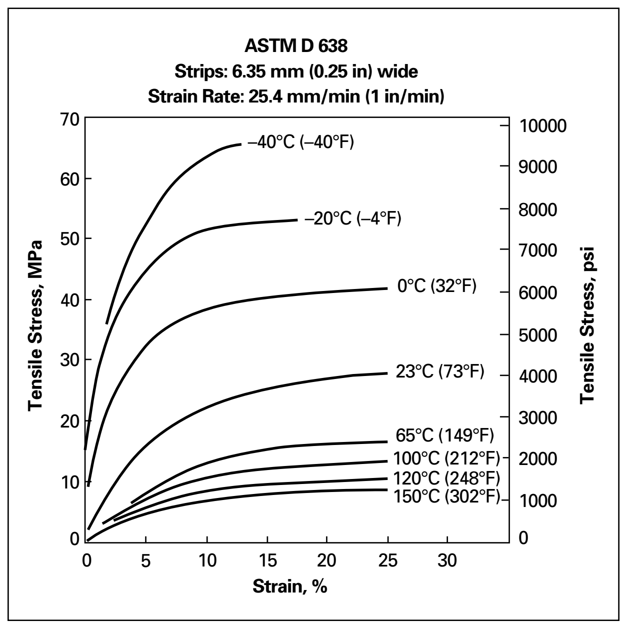


Figure 10. Tensile Stress at Low Strain—Hytrel 7246

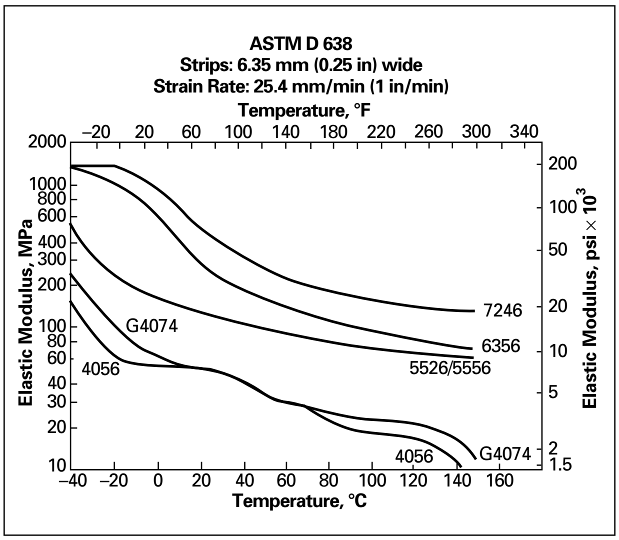


Elastic Modulus in Tension (ASTM D 638)

The elastic modulus is calculated from the linear portion of the stress-strain curves, that is, below the elastic limit, which is approximately between 7 and 10% strain for Hytrel. This modulus changes with time under load (see creep data), and this factor must be included in the calculation for part design.

This modulus is the ratio of stress to corresponding strain below the proportional limit of a material. This is also known as modulus of elasticity, or Young's modulus, and is a measure of a material's stiffness. It is represented in **Figure 11**.

Figure 11. Elastic Modulus in Tension versus Temperature—Hytrel



Tensile Set (ASTM D 412)

Tensile set represents residual deformation which is partly permanent and partly recoverable after stretching and retraction. For this reason, the periods of extension and recovery and other test conditions must be controlled to obtain comparable results. Tensile sets of representative Hytrel grades are shown in **Figures 12** and **13**.

Figure 12. Tensile Set—Hytrel

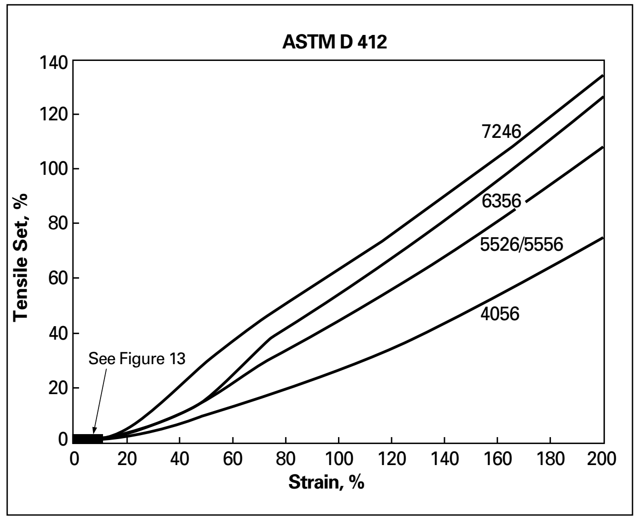
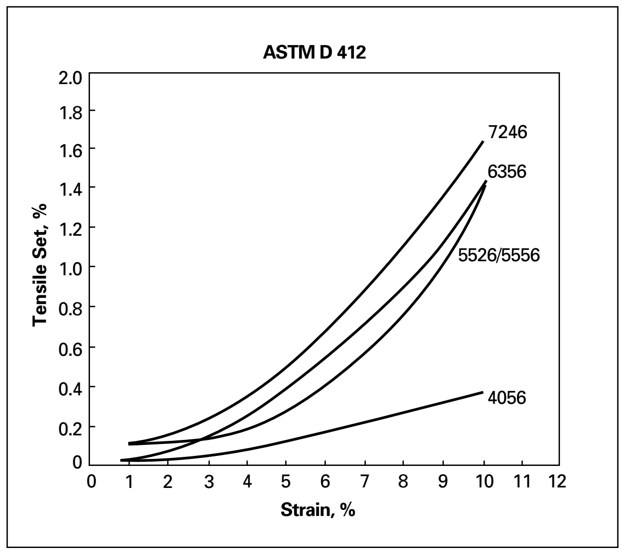


Figure 13. Tensile Set at Low Strain—Hytrel



Poissons' Ratio

Poissons' ratio measures the relative ability of a material to deform at right angles to applied stress. It permits the mathematical determination of a material's physical characteristics and values in a direction perpendicular to the direction of loading.

Poissons' ratio is defined as the ratio of the transverse strain to the longitudinal strain of a material. For plastics, the ratio is affected by time, temperature, stress, sample size, etc.

Poissons' ratio for most Hytrel resins at 23°C (73°F) is 0.45. The value does not change significantly from Hytrel resin to resin.

Compressive Properties (ASTM D 575)

Compressive properties describe the behavior of a material when it is subjected to a compressive load at a relatively low and uniform rate of loading. Properties in compression are generally stronger than in tension. In practical applications, the compressive loads are not always applied instantaneously. The results of impact, creep, and fatigue tests must also be considered during part design.

Table 3 lists the compression set values at different temperatures. Compression set can be significantly improved by annealing for 24–48 hr at 100°C (212°F) for Hytrel G4074 and 4056 and at 121°C (250°F) for all other Hytrel types.

Compressive stress-strain properties are obtained by using ASTM D 575, "Rubber Properties in Compression." Two molded discs of 28.6 mm (1.13 in) diameter and 6.25 mm (0.25 in) high are stacked together and placed in a compression testing apparatus.

Figures 14–18 illustrate the compressive stress versus strain properties generated by the use of this method at various temperatures.

Figure 14. Compressive Properties—Hytrel G4076

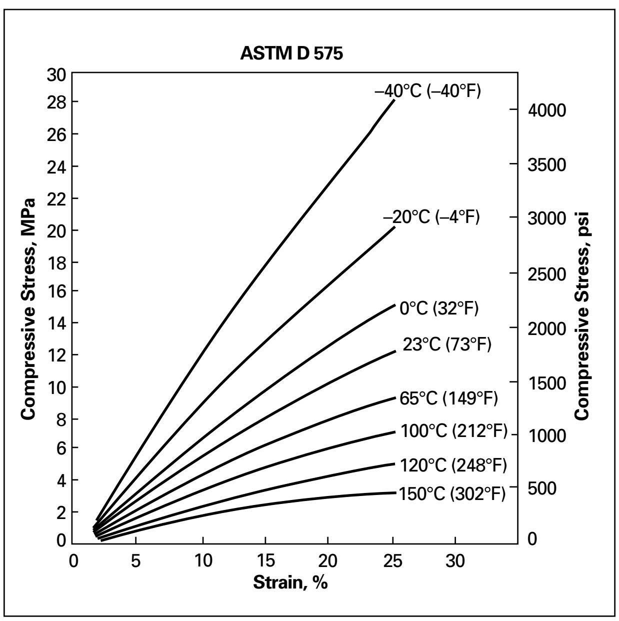


Table 3
Compression Set Resistance
ASTM D 395, Method A, 9.3 MPa (1350 psi) Load

	Compression Set, % After 22 hr at		
Type of Hytrel	**23°C (73°F)**	**70°C (158°F)**	**100°C (212°F)**
4056	11	27	33
G4074	10	28	51
5526/5556	<1	4	8
6356	<1	2	4
7246	<1	2	5

Figure 15. Compressive Properties—Hytrel 4056

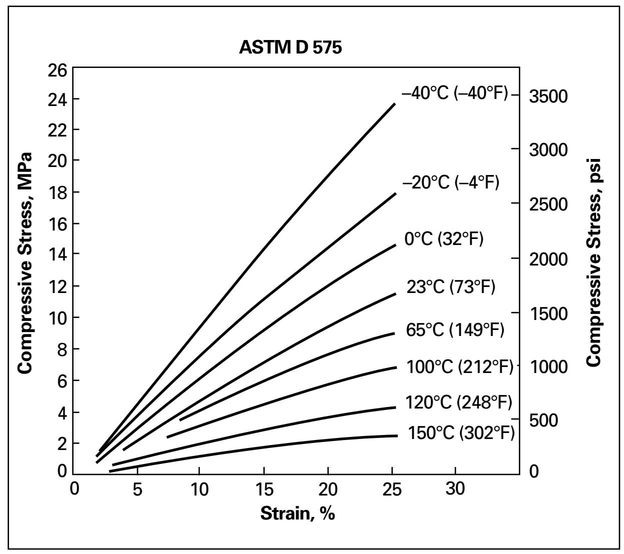


Figure 16. Compressive Properties—Hytrel 5526/5556

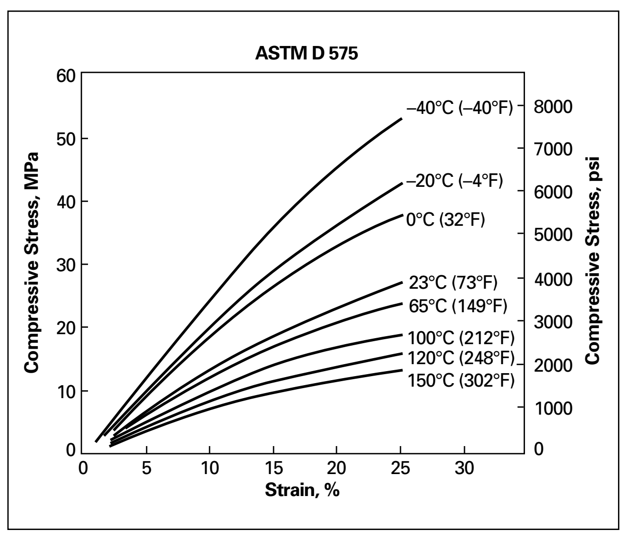


Figure 17. Compressive Properties—Hytrel 6346

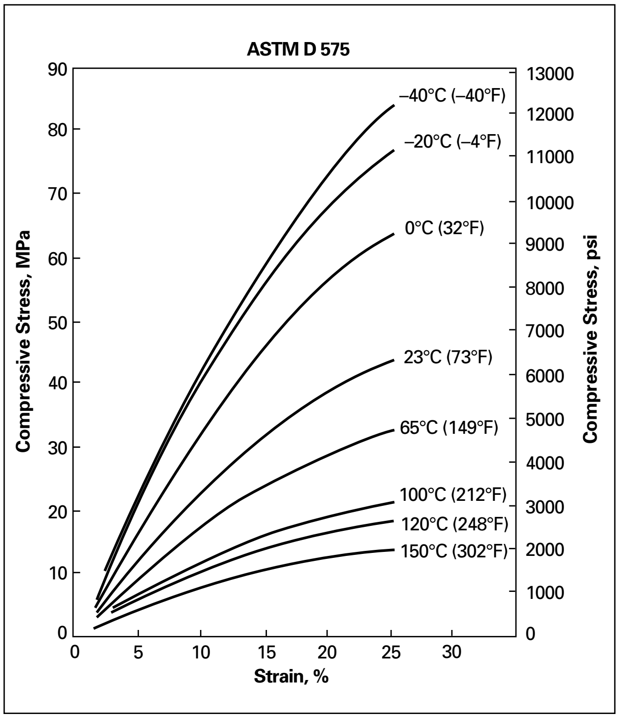
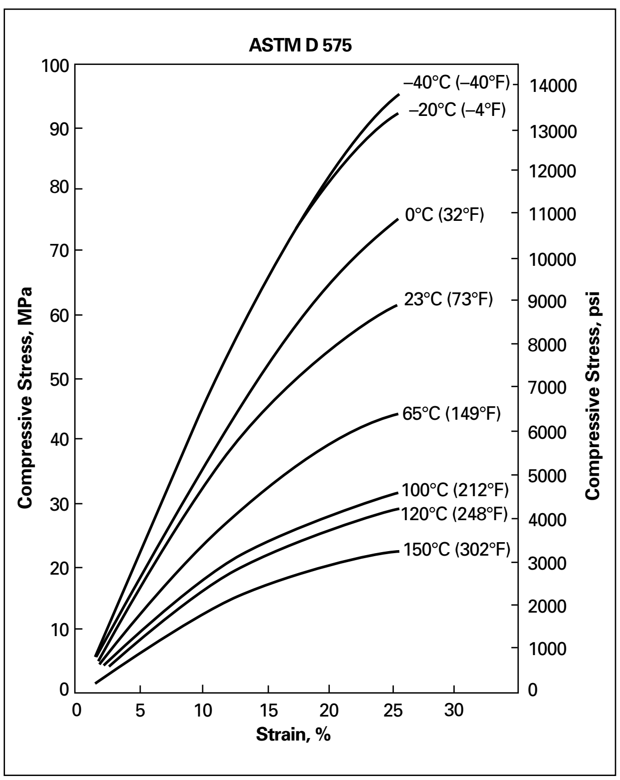


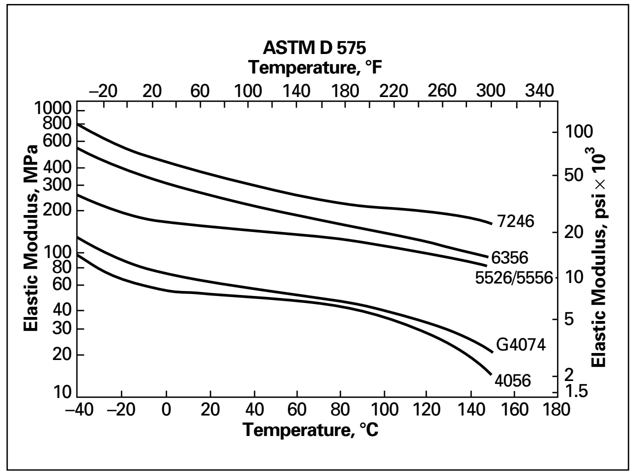
Figure 18. Compressive Properties—Hytrel 7246



Elastic Modulus in Compression

Figure 19 shows values for elastic modulus in compression versus temperature. These numbers are calculated from the linear portions of the stress-strain curves, that is, those portions below the elastic limit, which is approximately 7–10% for Hytrel. Modulus changes with time under load, however, and this factor must be included in part design.

Figure 19. Elastic Modulus in Compression versus Temperature—Hytrel



Flexural Properties (ASTM D 790)

The stress-strain behavior of polymers in flexure is of interest to anyone designing a part to be bent. Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. The stress induced due to the flexural load is a combination of compressive and tensile stress. Flexural properties are reported and calculated in terms of the tangent modulus of elasticity (or modulus of elasticity in bending).

Flexural Modulus

Variation of flexural modulus with temperature is shown in **Figure 20**. Differences in modulus values for tension, compression, and flexure will occur due to differences in strain rates, shapes of samples, etc. Also, flexure tests emphasize the surface of the sample, which will have molded-in stresses that are different from those in the interior of the sample, which cools more slowly in the molding process.

Creep Modulus (ASTM D 2990)

An important factor to consider when designing with thermoplastics is that the modulus of a given material will change due to many factors including stress level, temperature, time, and environmental conditions. **Figures 21–24** are plots of creep or apparent modulus versus time at various stress levels, all at room temperature. Generally, linear creep modulus plots can be extrapolated by a factor of ten in the time axis with reasonable safety. This has been done on the creep modulus plots and is signified by dashed lines. For critical applications, however, testing for the full expected life of the part should be done to verify these results. The highest stress level shown on each plot is the maximum recommended stress level for each material under long-term loading. Higher stress levels may result in catastrophic failure of the part. In all cases, testing should be performed on the fabricated part to verify satisfactory performance of the material in each application.

Figure 25 presents limited creep modulus data at 100°C (212°F). These plots are *not* extrapolated due to the unpredictable effects that heat aging under stress can have on materials.

Figure 20. Flexural Modulus versus Temperature—Hytrel

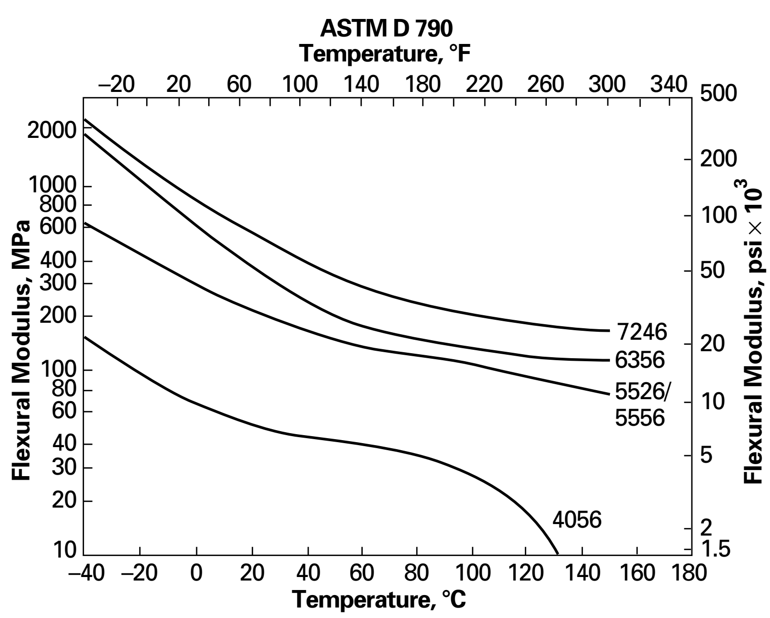


Figure 21. Tensile Creep Modulus—Hytrel 4056

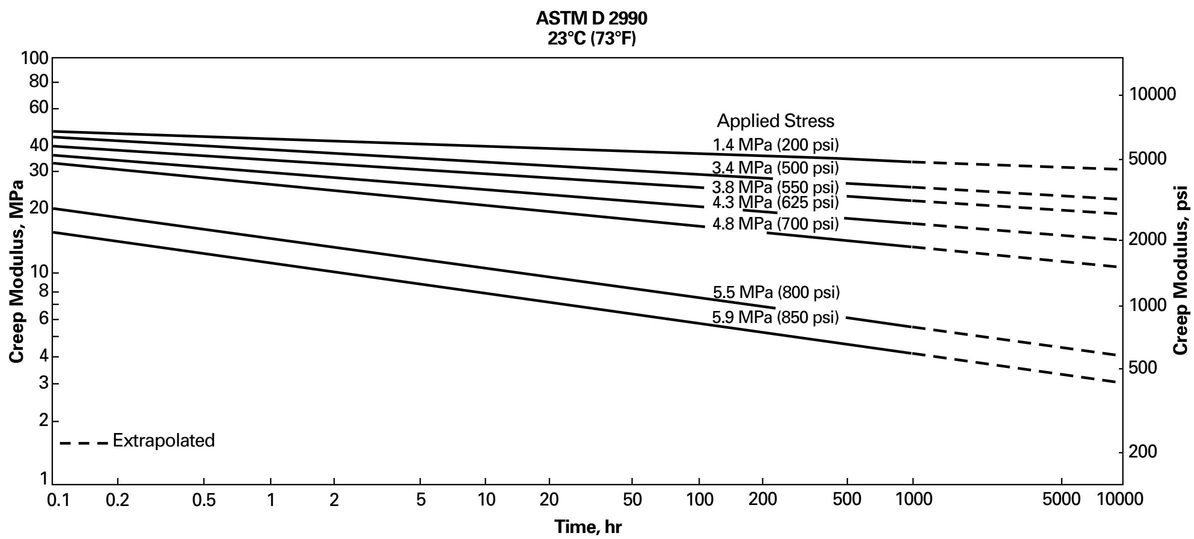


Figure 22. Tensile Creep Modulus—Hytrel 5526/5556

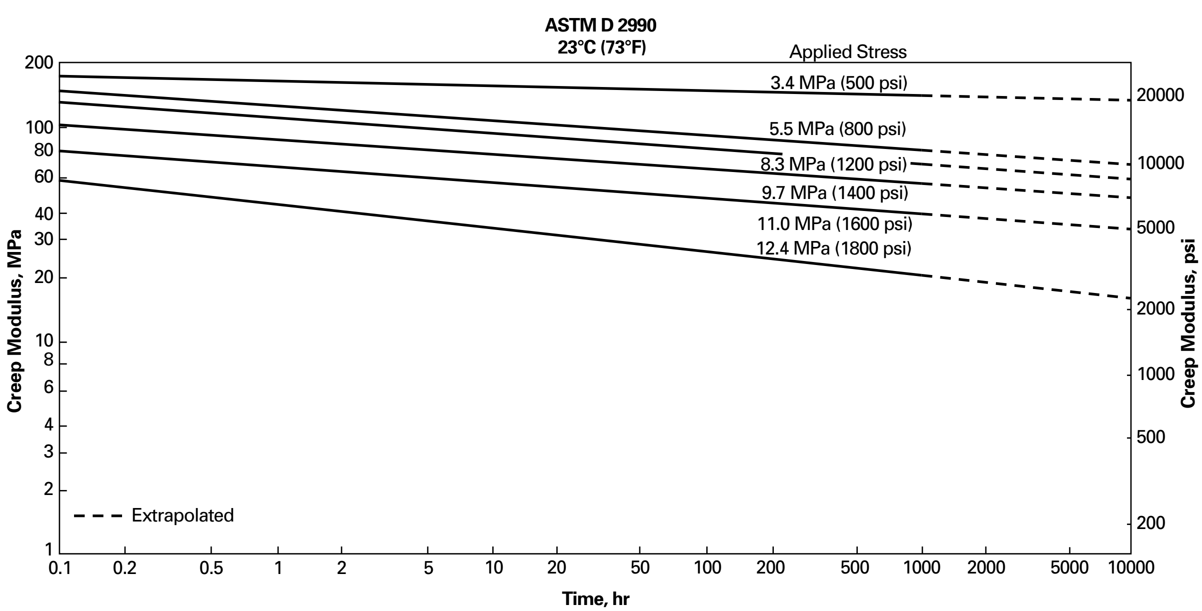


Figure 23. Tensile Creep Modulus—Hytrel 6356

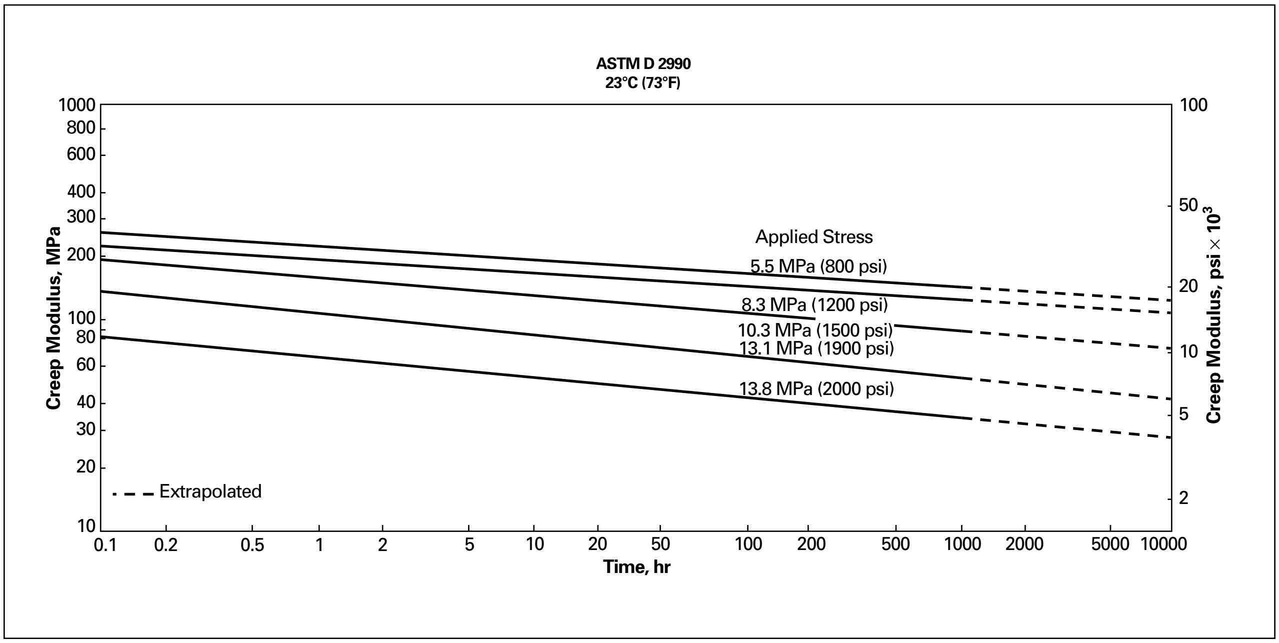


Figure 24. Tensile Creep Modulus—Hytrel 7246

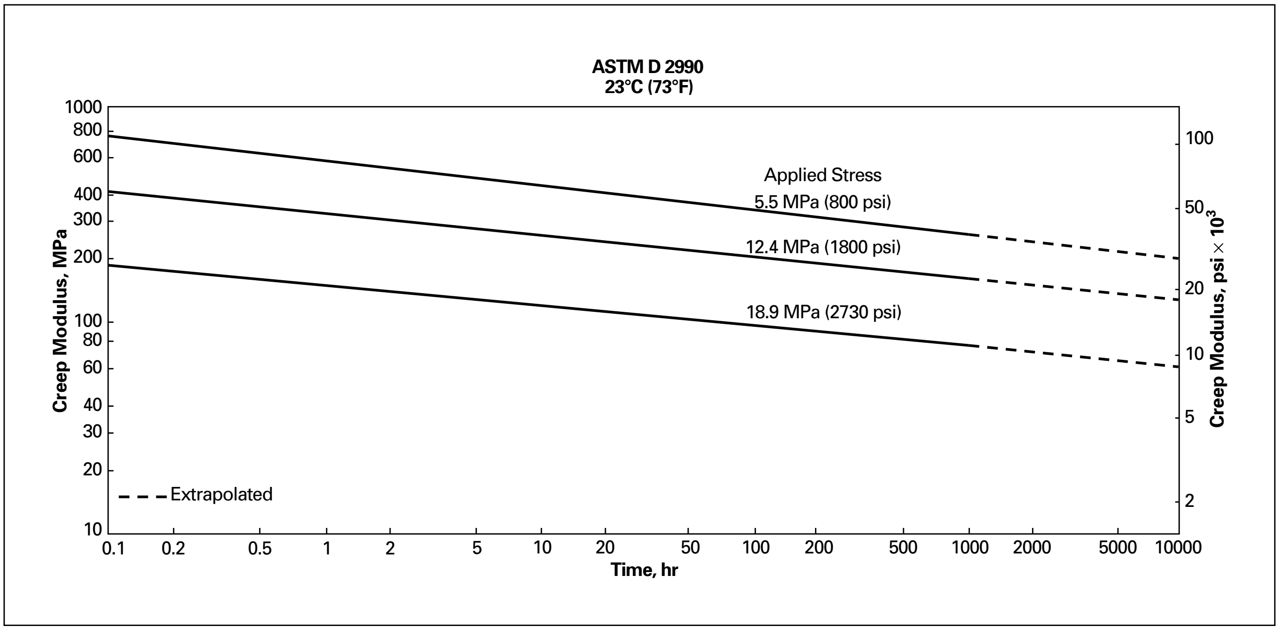
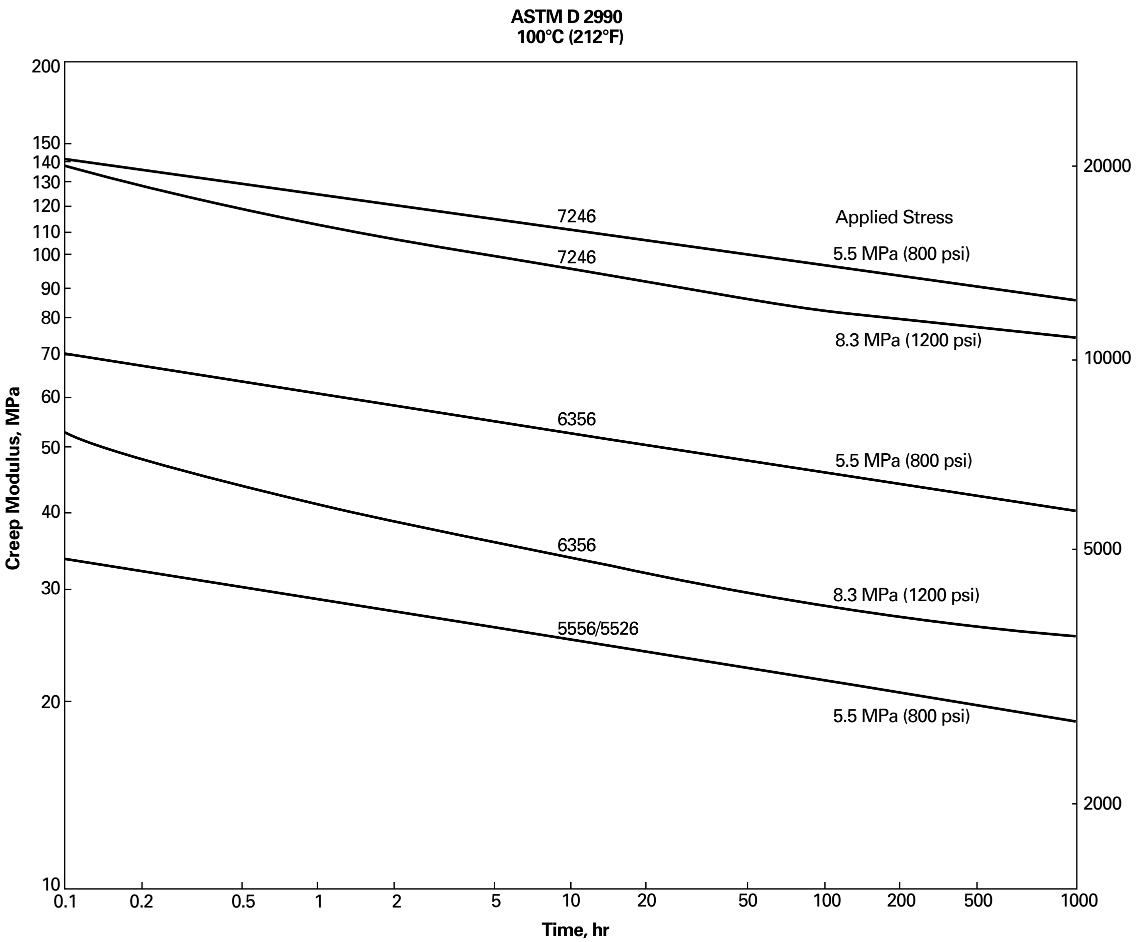


Figure 25. Tensile Creep Modulus at 100°C (212°F)—Hytrel



Compressive Creep

Compressive creep results for a load of 6.9 MPa (1000 psi) at 23°C (73°F) and 50°C (122°F) are presented in **Table 4**. Creep in compression is much less than in tension, as can be seen by comparing the values for compressive creep with those for tensile creep shown in the same table. Values for tensile creep were obtained by converting creep modulus data to creep strain with the formula:

$$\text{Creep strain} = \frac{\text{stress}}{\text{creep modulus}}$$

Table 4
Creep Strain
100 hr at 6.9 MPa (1000 psi) Stress

Type of Hytrel	Compressive Creep, % 23°C (73°F)	Compressive Creep, % 50°C (122°F)	Tensile Creep, % 23°C (73°F)
4056	5.4	8.9	—
G4074	6.0	11.5	—
5526/5556	0.6	1.3	8.0
6356	0.5	0.7	5.8
7246	0.5	0.5	2.5

Fatigue Resistance

The behavior of materials subjected to repeated cycle loading in terms of flexing, stretching, compressing, or twisting is generally described as fatigue. Such repeated cyclic loading eventually constitutes a permanent mechanical deterioration and progressive fracture, which can lead to complete failure. Fatigue life is defined as the number of cycles of deformation required to bring about the failure of the test specimen under a given set of oscillating conditions.

Flexural Fatigue (ASTM D 671)

The ability of a material to resist permanent deterioration from cyclic stress is measured in this test by using a fixed cantilever-type testing machine capable of producing a constant amplitude of force on the test specimen each cycle. The specimen is held as a cantilever beam in a vice at one end and bent by a concentrated load applied through a yoke fastened to the opposite end. The alternating force is produced by the unbalanced, variable eccentric mounted on a shaft. A counter is used to record the number of cycles along with a cutoff switch to stop the machine when the specimen fails.

Table 5 lists the fatigue limits of four types of Hytrel. Sample size and shape, frequency of flexing, ambient temperature, and heat transfer all have significant effects on fatigue.

For design purposes, a test simulating actual end-use conditions should be performed to determine the expected fatigue limit.

Table 5
Flex Fatigue
ASTM D 671

	Fatigue Limit*	
Type of Hytrel	**MPa**	**psi**
4056	5.2	750
5556	6.9	1000
6356	6.9	1000
7246	11.0	1600

*Samples tested to 2.5×10^6 cycles without failure.

Heat Generation and Flexural Fatigue in Compression (ASTM D 623)

Because of wide variations in service conditions, no correlation between accelerated test and service performance exists. This test helps to estimate relative service quality of Hytrel. It may be used to compare the fatigue characteristics and rate of heat generation when Hytrel is subjected to dynamic compressive strain.

In this method, which uses the Goodrich Flexometer, a definite compressive load is applied to a test specimen through a lever system having high inertia, while imposing on the specimen an additional high-frequency cyclic compression of definite amplitude. The increase in temperature at the base of the test specimen is measured.

Table 6 gives data on the temperature rise due to hysteresis after 20 min for two grades of Hytrel. Temperature rises fairly quickly and then remains roughly constant for the balance of the test.

Table 6
Goodrich Flexometer
ASTM D 623
2.54 mm (0.1 in) Stroke, 1.0 MPa (145 psi)
Static Load, 23°C (73°F)

	Sample Temperature After 20 min	
Type of Hytrel	**°C**	**°F**
4056	48	118
5556	66	151

Resistance to Flex Cut Growth

This test gives an estimate of the ability of Hytrel to resist crack growth of a pierced specimen when subjected to bend flexing. Due to the varied nature of operating service condition of a part molded in Hytrel, no correlation exists between these test results and actual end-use conditions.

Ross Flex (ASTM D 1052)

A pierced strip test specimen of 6.35 mm (0.25 in) thick is bent freely over a rod to a 90° angle and the cut length is measured at frequent intervals to determine the cut growth rate. The cut is initiated by a special shape piercing tool.

The test results are reported in **Table 7** as the number of cycles it took the specimen to grow five times the original pierced length. These results are also reported in **Table 2**, Typical Properties of Hytrel.

Table 7
Resistance to Flex Cut Growth, Ross (Pierced)
ASTM D 1052
Cycles to Five Times Cut Growth

Type of Hytrel	23°C (73°F)
G3548W	$>1 \times 10^6$
G4074, G4078W	$>1 \times 10^6$
G4774, G4778	$>1 \times 10^6$
G5544	8×10^5
4056	$>1 \times 10^6$
4069	$>1 \times 10^6$
4556	$>1 \times 10^6$
5526, 5556	5×10^5
6356	5×10^5
7246	3×10^4
8238	—
HTR3078	$>1 \times 10^6$
HTR4275BK	5×10^4
5555HS	1×10^5
HTR5612BK	6×10^5
HTR6108	6×10^5
HTR8068	—
HTR8139LV	$>1 \times 10^6$
HTR8171	$>1 \times 10^6$
HTR8206	—

DeMattia Flex (ASTM D 813)

A pierced strip test specimen of 6.35 mm (0.25 in) thick with a circular groove restrained so that it becomes the outer surface of the bend specimen, with 180° bend, and the cut length is measured at frequent intervals to determine the cut growth rate.

The test results are reported in **Table 8** as the number of cycles it took for the specimen to reach failure.

Table 8
De Mattia Flex Life (Pierced)
ASTM D 813
Cycles to Failure

Type of Hytrel	23°C (73°F)
G3548W	3.6×10^4
G4074, G4078W	3.6×10^4
G4774, G4778	1.6×10^5
G5544	7×10^3
4056	$>1 \times 10^6$
4069	1.7×10^5
4556	3.6×10^3
5526, 5556	$>1 \times 10^6$
HTR4275BK	5.4×10^4
HTR5612BK	1.1×10^5
HTR6108	5.4×10^3

Impact Resistance

The impact properties of polymeric materials are directly related to their overall toughness, which is defined as the ability of the polymer to absorb applied energy. Impact resistance is the ability of a material to resist breaking under shock loading or the ability to resist the fracture under stress applied at high speed.

Most polymers, when subjected to impact loading, seem to fracture in a characteristic fashion. The crack is initiated on the polymer surface by the impact loading. The energy to initiate such a crack is called the crack-initiation energy. If the load exceeds the crack-initiation energy, the crack continues to propagate. A complete failure occurs when the load exceeds the crack-propagation energy. Thus, both crack initiation and crack propagation contribute to the measured impact strength.

The speed at which the specimen or part is struck with an object has a significant effect on the behavior of the polymer under impact loading. At low rates of impact, relatively stiff material can still have good impact strength; while at high rates of impact, even highly elastomeric material like Hytrel may exhibit brittle failure at low temperatures. All materials have a critical velocity in which they behave as glassy, brittle materials.

Impact properties are highly dependent on temperature. Generally, plastics are tougher and exhibit ductile modes of failure at temperatures above their glass transition temperature (T_g), and are brittle well below their T_g.

A notch in a test specimen, which creates a localized stress concentration, or a sharp corner in a molded part drastically lowers impact strength.

Notched Izod Impact (ASTM D 256)

The objective of the Izod impact test is to measure the behavior of a standard notched test specimen to a pendulum-type impact load. The specimen is clamped vertically and the swinging pendulum is released with the notch on the opposite side. The results are expressed in terms of kinetic energy consumed by the pendulum in order to break the specimen. The energy required to break a standard specimen is actually the sum of energies needed to deform it, to initiate its fracture, and to propagate the fracture across it, and the energy needed to throw the broken ends of the specimen. These test results are reported in **Table 2**, pages 6–9, at room temperature and at –40°C (–40°F).

Instrumented Impact (ASTM D 3763)

One of the drawbacks of the conventional impact test method is that it provides only one value, the total impact energy; it does not provide data on the type of fracture (ductile, brittle), dynamic toughness, fracture, yield loads or fracture behavior based on the geometry of the specimen.

The falling weight instrumented impact tester provides a complete load and energy history of specimen fracture mechanism. Such a system monitors and precisely records the entire impact event, starting from the rest position to initial impact, plastic bending to fracture initiation, and propagations to complete failure.

Measurement is done by mounting the strain gauge into the striking tup, and an optical device triggers the microprocessor just before striking the specimen. The output of the strain gauge records the applied load variations to the specimen throughout the entire fracturing process. A complete load-time history (fracturing) of the entire specimen is obtained. The apparent total energy absorbed by the specimen is calculated and plotted against time.

Figures 26–30 show drop-weight-impact results for representative grades of Hytrel. The plots show energy dissipated in rupturing the sample, and the maximum force experienced by the tup as it punches through the sample.

Figure 26. Drop Weight Impact Failure Energy versus Temperature—Hytrel

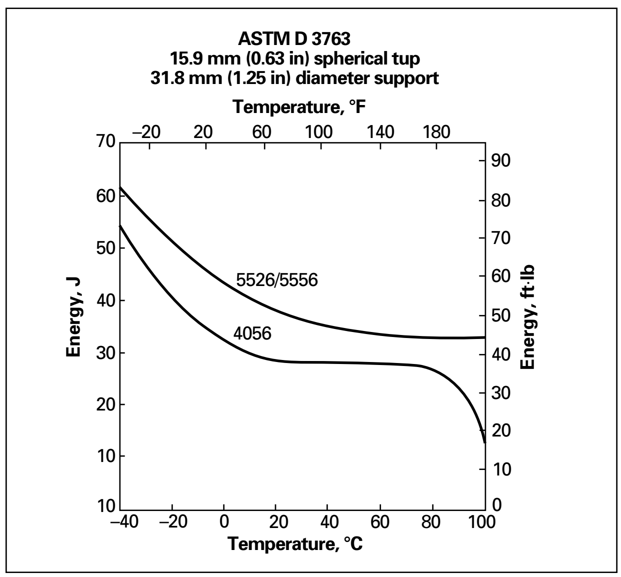


Figure 27. Drop Weight Impact Failure Energy versus Temperature—Hytrel

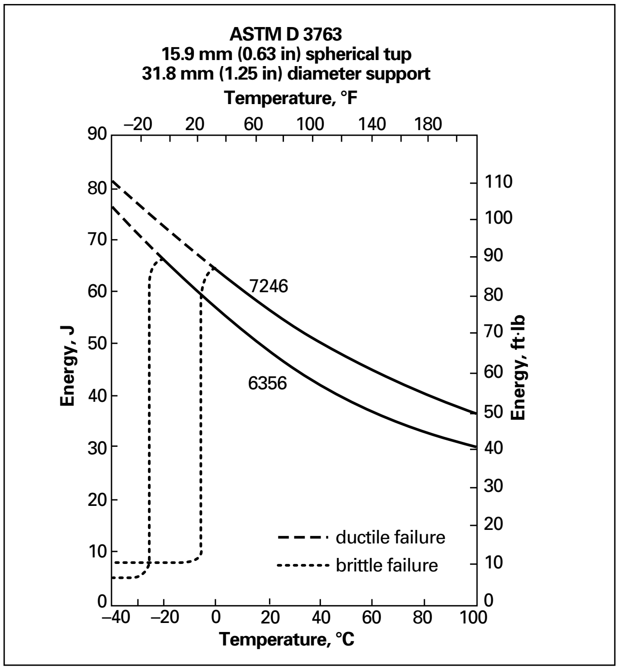


Figure 28. Drop Weight Impact Failure Load versus Temperature—Hytrel

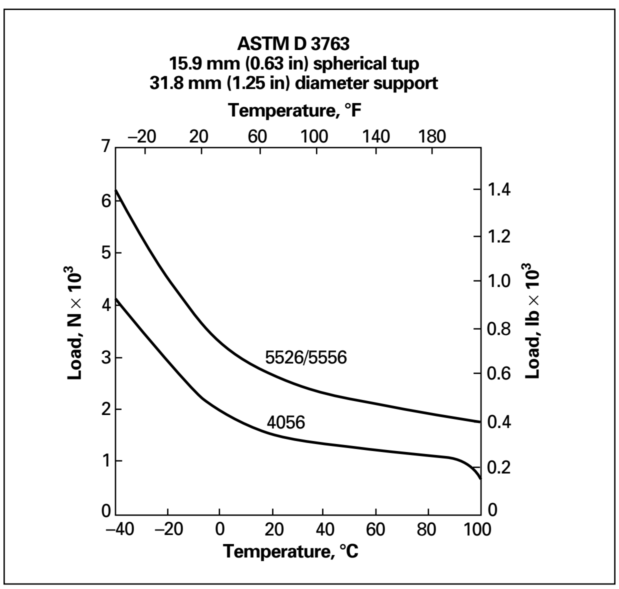


Figure 29. Drop Weight Impact Failure Load versus Temperature—Hytrel

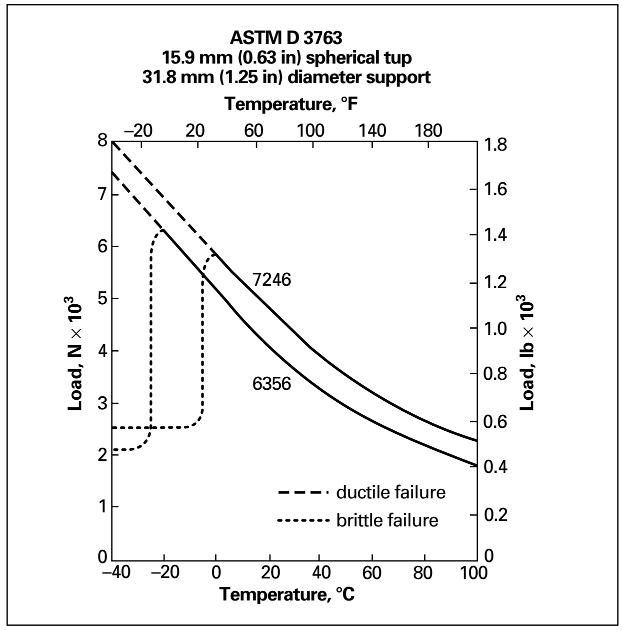
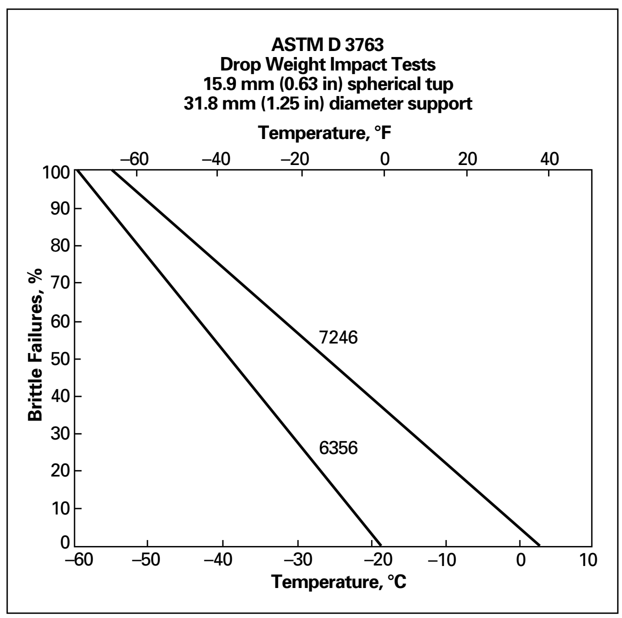


Figure 30. Percentage of Brittle Failures versus Temperature—Hytrel



Brittleness Temperature (ASTM D 746)

This test method establishes the temperature at which 50% of the specimens tested fail when subjected to the test conditions. The test evaluates long-term effects such as crystallization. Thermoplastic elastomers are used in many applications requiring low-temperature flexing with or without impact. Data obtained by this test may be used to predict the behavior of elastomeric materials at low temperatures only in applications in which the conditions of deformation are similar to the test conditions. **Table 9** lists the brittleness temperatures for representative grades of Hytrel.

Table 9
Brittleness Temperature
ASTM 746

	Brittleness Temperature	
Type of Hytrel	**°C**	**°F**
G3548W	–60	–76
G4074, G4078W	–66	–87
G4774	–56	–67
G4778	–65	–85
G5544	–60	–76
4056	<–100	<–148
4069	<–105	<–157
4556	<–105	<–157
5526	<–70	<–96
5556	<–70	<–96
6356, 7246	<–70	<–94
8238	–92	–134
3078	<–105	<–157
HTR4275BK	<–70	<–94
5555HS	<–70	<–94
HTR5612BK	<–70	<–94
HTR6108	–98	–144
HTR8068	–48	–51
HTR8139LV	<–100	<–148
HTR8171	–63	–81
HTR8206	–67	–88

Chapter 3

Thermal Properties

Contents

Thermal Conductivity and Specific Heat

Thermal conductivity data are shown in **Table 10**, and coefficients of linear thermal expansion in the flow direction measured by TMA (Thermo Mechanical Analysis) are presented in **Table 11. Figure 31** is a plot of specific heat versus temperature for four types of Hytrel.

Table 10
Thermal Conductivity

	Thermal Conductivity *(k)*	
Type of Hytrel	**J/sec·m·°C**	**Btu/hr·ft·°F**
G4074	0.165	0.095
4056	0.190	0.110
5526/5556	0.156	0.090
6356	0.152	0.088
7246	0.149	0.086

Table 11
Coefficient of Linear Thermal Expansion, SI Units

Type of Hytrel	Temperature Range, °C	Coefficient mm/mm/°C × 10^{-5}
4056	–40–23	15
	23–55	13
	55–100	11
5526/5556	–50–23	18
	23–55	20
	55–120	21
7246	–40–23	13
	23–55	17
	55–120	11

Dynamic Properties (ASTM D 2236)

These measurements are made by DMA (Dynamic Mechanical Analysis) technique. The measurements are made at varying temperatures. The dynamic modulus represented in **Figure 32** represents the load-bearing capability or stiffness of the plastic materials, while the tan δ or the damping factor represented in **Figure 33** represents the glass transition temperature, below which the plastic goes into a glassy state. These data are useful in the design of parts used in dynamic applications such as motor mounts and couplings.

Figure 31. Specific Heat versus Temperature—Hytrel

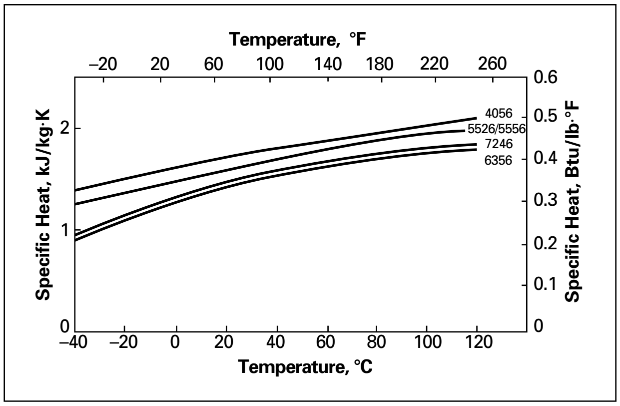


Figure 32. Dynamic Modulus versus Temperature—Hytrel

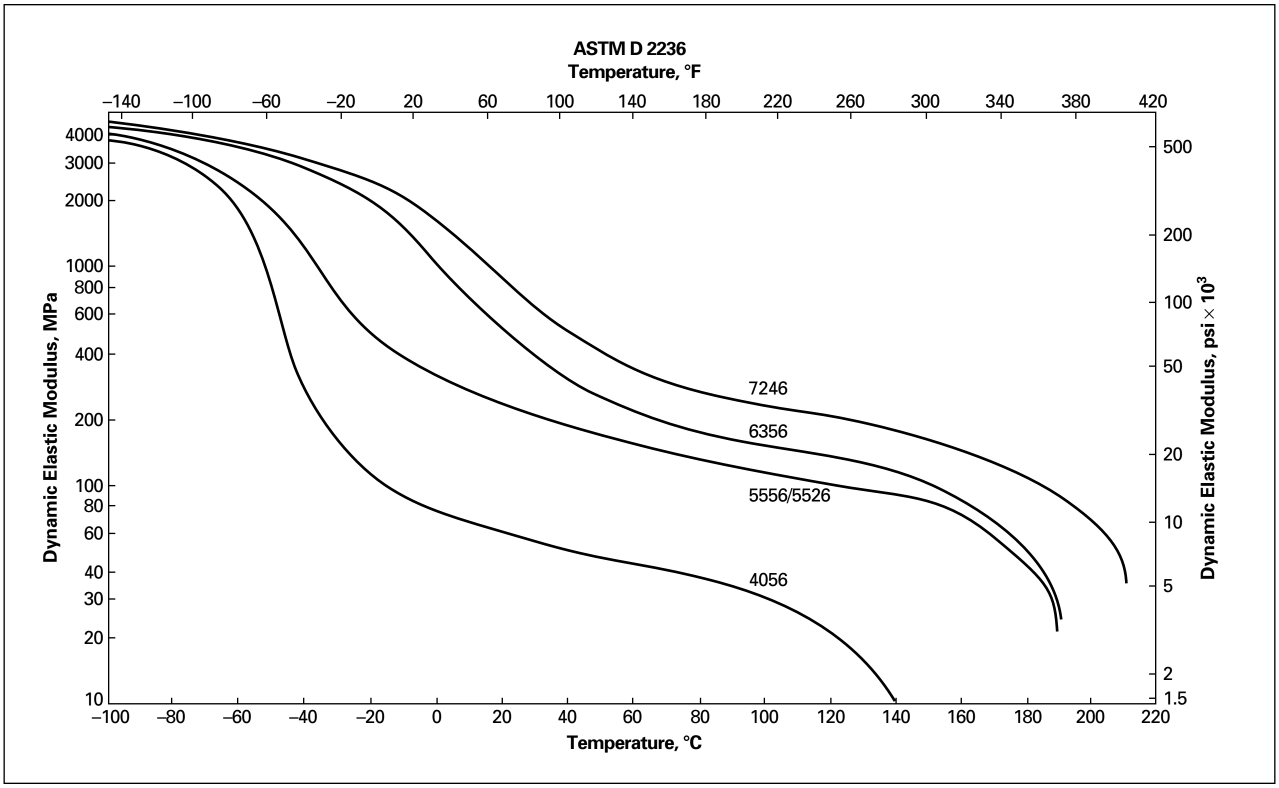
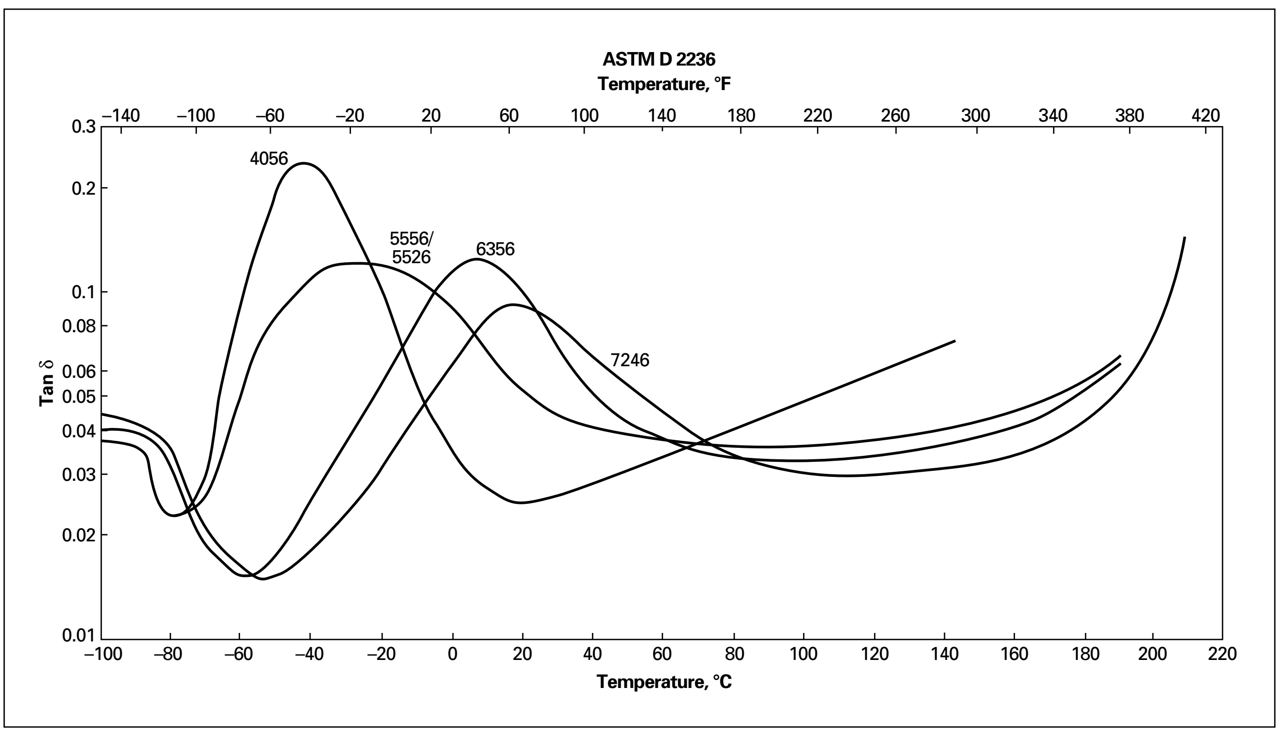


Figure 33. Damping Factor versus Temperature—Hytrel



Chapter 4

Electrical Properties

Contents

Electrical Properties

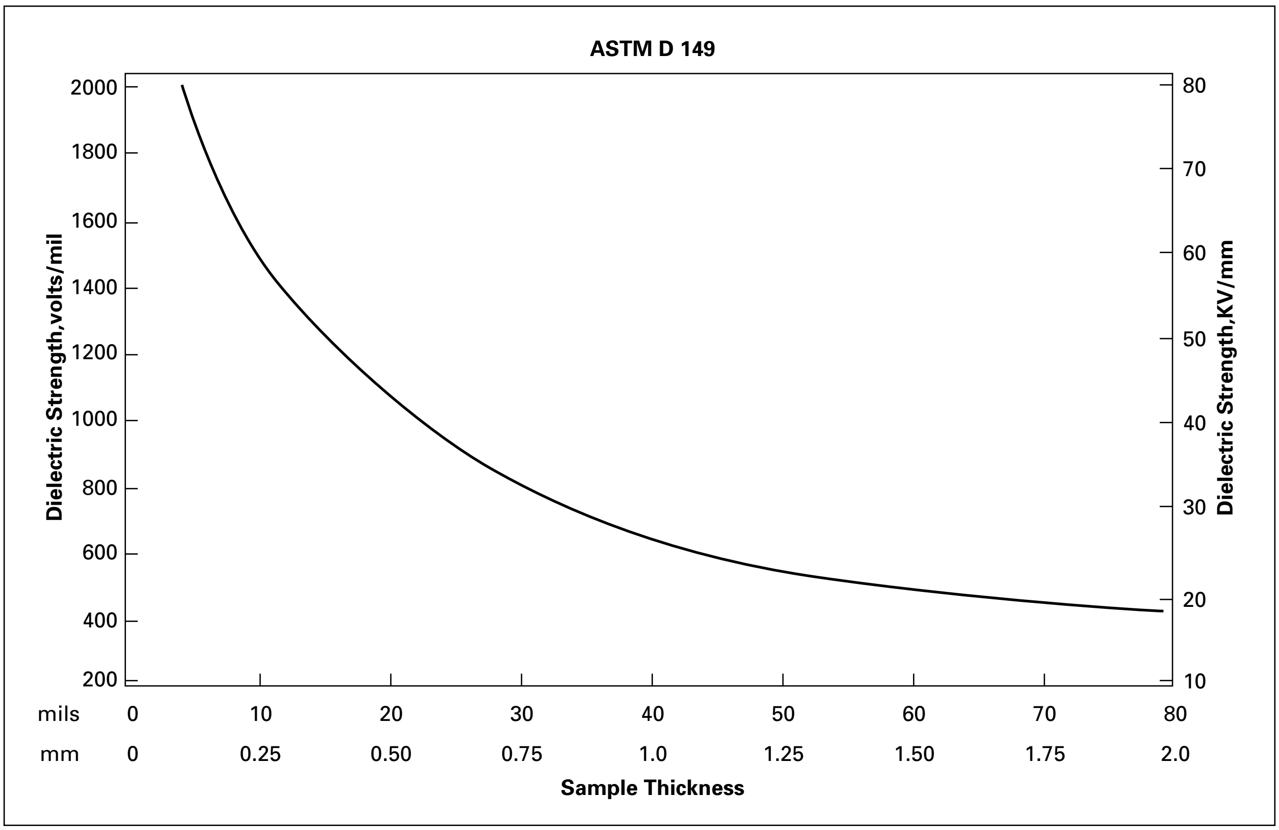
Electrical measurements show that Hytrel engineering thermoplastic elastomers are suitable for low-voltage applications. High-mechanical strength, coupled with excellent resistance to oils, solvents, and chemicals, also makes Hytrel suitable for many jacketing applications. The properties shown in **Table 12** were measured on injection molded plaques with the dimensions 76 × 127 × 1.9 mm (3 × 5 × 0.075 in).

As with all polymeric materials, the dielectric strength in kV/mm (V/mil) varies depending on the sample thickness used in the measurement. **Figure 34** shows this relationship for Hytrel 5556. The same relationship applies to all other grades.

Table 12
Electrical Properties at Room Temperature and 50% RH

Property	ASTM Test Method	Hytrel 4056	Hytrel 5526	Hytrel 5556	Hytrel 6356	Hytrel 7246
Volume Resistivity, Ω·cm	D 257	8.2×10^{10}	1.2×10^{11}	1.1×10^{11}	9.7×10^{11}	1.8×10^{12}
Dielectric Strength, kV/mm (V/mil)	D 149	16.1 (410)	17.3 (440)	15.7 (400)	16.1 (410)	18.1 (450)
Dielectric Constant	D 150					
0.1 kHz		5.2	4.5	4.6	4.4	4.0
1 kHz		5.1	4.5	4.5	4.2	3.9
1000 kHz		4.6	4.2	4.1	3.7	3.5
Dissipation Factor	D 150					
0.1 kHz		0.005	0.006	0.006	0.018	0.016
1 kHz		0.008	0.009	0.009	0.02	0.019
1000 kHz		0.06	0.04	0.04	0.04	0.03

Figure 34. Dielectric Strength vs. Thickness—Hytrel 5556



Chapter 5

Abrasion and Wear

Contents

Friction

Measurements of frictional properties may be made on a film or sheeting specimen when sliding over itself or over another substance. The coefficients of friction are related to the slip properties of plastics.

The coefficient of friction—the ratio of the frictional force to the force, usually gravitational, acting perpendicular to the two surfaces in contact. This coefficient is a measure of the relative difficulty with which the surface of one material will slide over an adjoining surface of itself, or of another material. The static or starting coefficient of friction is related to the force measured to begin movement of the surfaces relative to each other. The kinetic or dynamic or sliding coefficient of friction is related to the force measured in sustaining this movement.

Values for the coefficient of friction of Hytrel measured by two different methods are shown in **Table 13**. As can be seen from the data, test methods have a great influence on the results; therefore, it is difficult to predict frictional forces unless testing is performed under conditions that simulate the end use.

Wear (ASTM D 1044, Modified)

Measurement of wear is determined by the weight loss and/or thickness loss on the test specimen under the force of abrasive wheel held under specified load against the test specimen mounted on a rotating turntable.

Hytrel engineering thermoplastic elastomer has excellent wear properties in many applications. **Table 14** lists results from Taber and NBS abrasion tests. For information on wear in bearing applications, see “Bearings and Seals,” page 62.

Table 13
Coefficient of Friction

	Hytrel on Steel Moving Sled—ASTM D 1894	Hytrel on Steel Thrust Washer—ASTM D 3702
Type of Hytrel	**Static**	**Dynamic**
4056	—	0.82
5526/5556	0.32	0.44
6356	0.26	0.31
7246	0.22	0.28

Table 14
Abrasion Resistance
ASTM D 1044
mg/1000 rev

	Taber Abrasion	
Type of Hytrel	**CS-17 Wheel**	**H-18 Wheel**
G4074	9	193
4056	3	100
5526/5556	6	64
6356	7	77
7246	13	47

Chapter 6

Effect of Environment

Contents

Moisture Pickup and Drying

Hytrel granules are supplied in moisture-resistant packaging. However, when exposed to air, the granules pick up moisture. Moisture levels above 0.10% may seriously impair the processing, causing highly variable melt pressure, varying extruder output, degradation of the resin, and, possibly, bubbles in the melt as it exits the die.

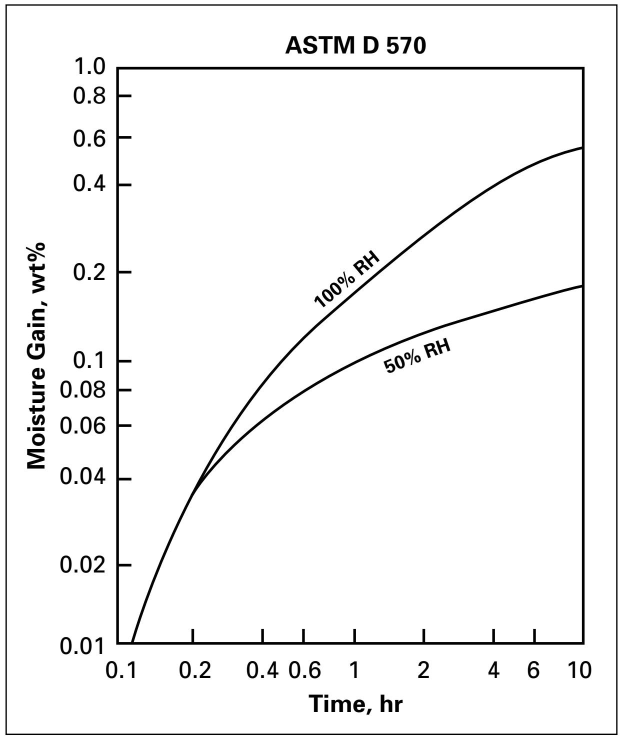
At temperatures above the melting point, excessive moisture causes hydrolytic degradation of the polymer. Such degradation results in poor physical properties and brittleness, particularly at low temperatures.

Equilibrium moisture levels depend on the grade and are shown in **Table 15** (ASTM D 570 test method). The rate of moisture absorption for Hytrel 5556 is shown in **Figure 35**.

Table 15
Equilibrium Moisture Levels of Hytrel

Type of Hytrel	Equilibrium Moisture Level, % After 24 hr
High Productivity	
G3548W	5.0
G4074	2.1
G4078W	3.0
G4774, G4778	2.5
G5544	1.5
High Performance	
4056	0.6
4069	0.7
4556	0.6
5526	0.5
5556	0.5
6356	0.3
7246	0.3
8238	0.3
Specialty	
3078	3.0
5555HS	0.7
HTR4275BK	0.3
HTR5612BK	0.4
HTR6108	0.2
HTR8068	1.9
HTR8139LV	0.7
HTR8171	54
HTR8206	30

Figure 35. Moisture Absorption at Ambient Temperature—Hytrel 5556

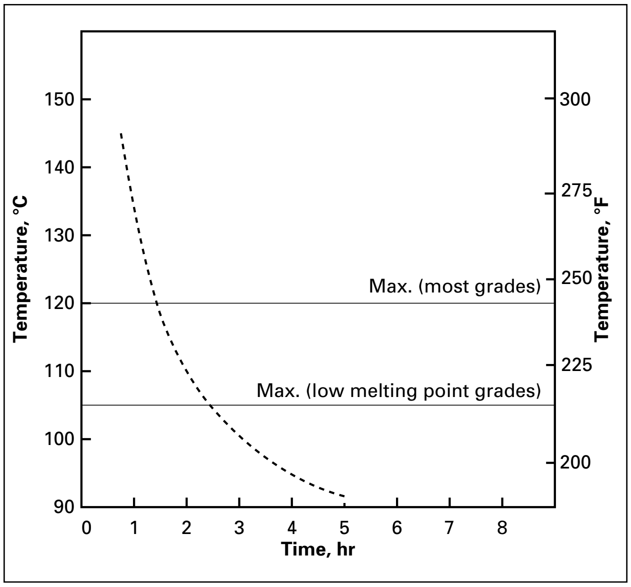


Hytrel thermoplastic elastomer must be dried prior to processing, which is critical to making quality parts that will give good service performance.

Also, in the case of critical extrusion operations, such as vacuum calibration of tubes to small tolerances, it has been found that extruder output may fluctuate slightly with changing moisture levels and temperature of the granules in the hopper. For this reason, drying of Hytrel granules in a desiccant (dehumidifying) drier under conditions of fixed temperature and time is recommended.

Drying time and temperature will depend on the initial moisture level in the material, as well as the type of drier or oven used. However, general guidelines for drying Hytrel, which are based on laboratory and industrial experience, are shown in **Figure 36**.

Figure 36. Recommended Guidelines for Drying Hytrel (Drying Time versus Temperature)



Shrinkage and Post-Molding Shrinkage

Shrinkage of Hytrel in injection molding depends on factors such as:

- Grade of Hytrel
- Molding conditions (injection pressure, screw forward time [SFT], mold temperature, etc.)
- Part geometry and thickness
- Mold design, runner, sprue system, gate size

Shrinkage is measured at room temperature and at 50% RH on a standard test specimen 24 hr after molding. Shrinkage increases significantly after molding, but tends to reach a maximum after 24 hr. This section provides information on how shrinkage varies with these parameters.

Unless stated, these shrinkage values were obtained on test specimens of 3.2 mm (0.125 in) thickness molded at standard conditions:

- Mold temperature: 45°C (113°F)
- Injection pressure: 70 MPa (10,150 psi)
- SFT: optimum

Table 16 gives the nominal shrinkage values for various grades of Hytrel, obtained under these standard conditions.

Table 16
Shrinkage of Hytrel
ASTM D 955
Measured on standard test specimen, in flow direction 3.2 mm (0.125 in) thick, molded at recommended conditions

Type of Hytrel	Shrinkage, %
Standard	
G3548W	0.5
G4074	0.8
G4078W	0.8
G4774, G4778	1.4
G5544	1.6
High-Performance	
4056	0.5
4069	0.8
4556	1.1
5526	1.4
5556	1.4
6356	1.5
7246	1.6
8238	1.6
Specialty	
5555HS	1.4

Figures 37–39 show the influences on shrinkage of different injection molding parameters. The data provides a general guideline to help in predicting shrinkage. The values should be added to or subtracted from the nominal shrinkages given in **Table 16** in order to get a first approximation of the final shrinkage. **The shrinkage evaluation for precision parts should be made on a prototype tool.**

Figure 37. Influence of Mold Temperature on Shrinkage

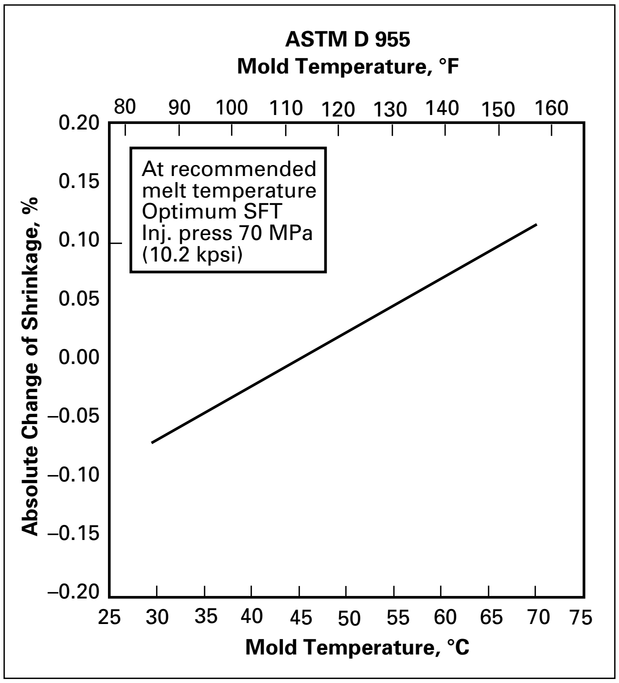


Figure 38. Influence of Part Thickness on Shrinkage in Length

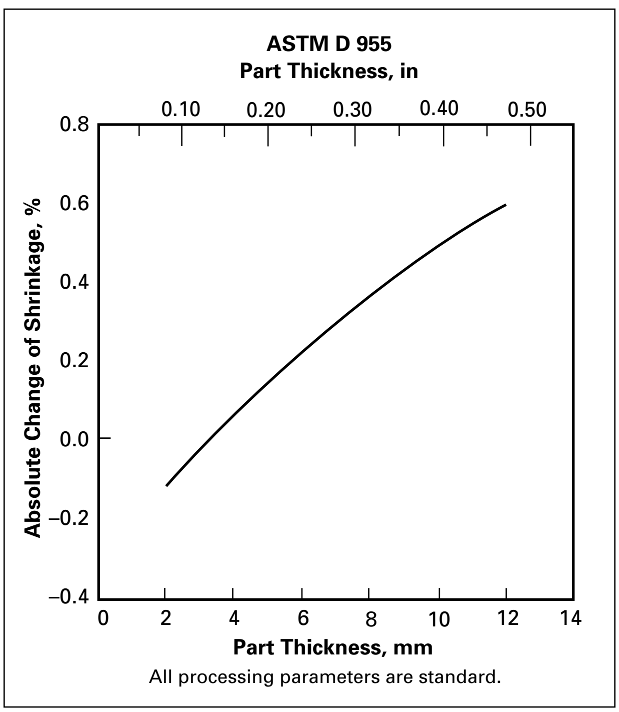
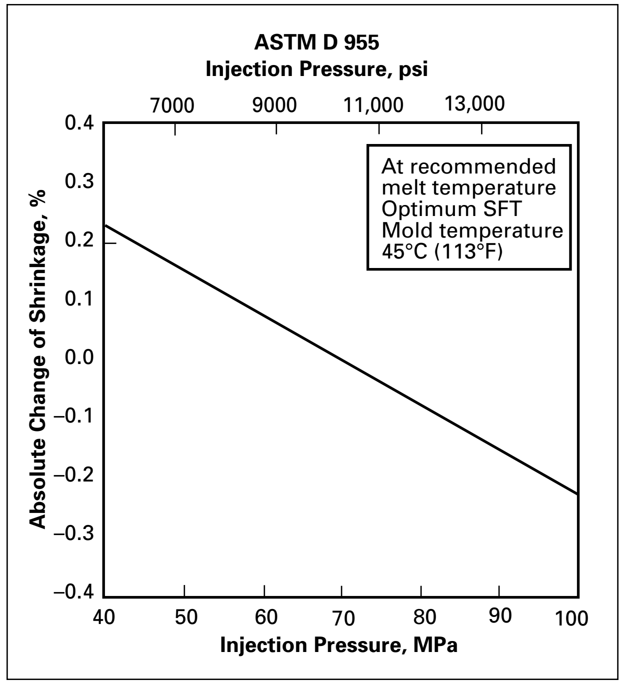


Figure 39. Influence of Injection Pressure on Shrinkage



For example, an approximation of the shrinkage of a part made of Hytrel can be done as follows:

Nominal shrinkage of Hytrel 5526:	1.40% (**Table 16**)
Part is molded using a 64°C mold temperature (versus 45°C):	0.08% (**Figure 37**)
Part has a thickness of 2 mm (versus 3.2 mm):	–0.13% (**Figure 38**)
Part is molded using an injection pressure of 900 bar (versus 700 bar):	–0.15% (**Figure 39**)
Total shrinkage is approximately:	**1.20%**

Annealing

Post-molding shrinkage is measured after annealing parts at 120°C (248°F) for 4 hr. Even for the stiffer and more crystalline grades, the absolute value of post-molding shrinkage for parts molded at recommended conditions is low (less than 0.1%).

Dimensional Tolerances

Allowable variations in the dimensions of an injection molded part are called the tolerances of the part and greatly affect the cost of manufacture. A realistic view of the purchased cost of tolerances often helps avoid high manufacturing charges with no detriment to the performance of the part.

Regardless of the economics, it may be unreasonable to specify close production tolerances on a part when it is designed to operate within a wide range of environmental conditions. Dimensional change due to temperature variations alone can be three to four times as great as the specified tolerances. Also, in many applications such as bearings and gears, close tolerances with plastics are not as vital as with metals, because of the resiliency of plastics.

Some general suggestions are:

- The design for a part should indicate conditions under which the dimensions shown must be held (temperature, humidity, etc.).
- On a drawing, overall tolerances for a part should be shown in mm/mm (in/in), not in fixed values. A title block should read, "All decimal dimensions ±0.00X mm/mm (±0.00X in/in), not ±0.00X mm (±0.00X in), unless otherwise specified."
- The number of critical dimensions per part should be as low as possible. A part with several critical dimensions will naturally be more difficult to mold than a part with few critical dimensions.
- Tight tolerances should not be put on dimensions across a parting line or on sections formed by movable cores or sliding cams.
- Where compromises in tolerances could be acceptable from a performance standpoint, the tolerances in question should be discussed with the molder in view of possible economics.

Factors that must be considered when establishing tolerances for injection-molded parts are:

- Thermal expansion and contraction
- Nature of the surroundings
- Processing conditions and part molding shrinkage
- Molding tolerances

Multicavity molds will result in a cost savings but can increase tolerance limits from 1–5% per cavity. Therefore, a tolerance that would be specified for a single-cavity mold would have to be increased to allow for production variables. Whether or not the part can withstand this variance will depend on the function of the part and should always be considered.

The ability to maintain minimum tolerances is dependent on part design, the number of cavities, mold design, the injection molding system used, molding conditions, and the ability of the molder. Only through an optimization of all of these variables can the tightest of tolerances be maintained.

The Molding Operation

In the injection molding of thermoplastics, parts are made by injecting molten resin into a shaped cavity that has been built into an appropriate mold. In the cavity, the molten resin is held under pressure until it solidifies. Simultaneously, it is shrinking due to the change from liquid to solid and thermal contraction. The solid part thus formed reproduces the cavity shape in detail and is removed from the mold. Ejector pins or rings in the mold free the part from it. Molten resin is produced by melting raw material in the cylinder of the molding machine while the part just formed is cooling in the mold.

This overall procedure is repeated on a rigidly maintained cycle until the required number of parts is produced. Cycle time is determined largely by the rate at which heat can be removed from the cooling part. This rate is approximately proportional to the wall thickness of the part and is slow because of low thermal conductivity. For this reason, parts should be designed with walls as thin as is consistent with design requirements and ease of fabrication.

The configuration and dimensions of the molding tool depend on the size and shape of the part to be produced as well as the number of cavities to be employed in production. At the same time, mold dimensions must be governed by the dimensions of standard molding machines. Mold costs often can be reduced by the use of standard mold frames into which the part-forming cavities are fitted.

The molding process and the injection mold offer the designer an opportunity to add both value and function to the design. A close relationship between the functional designer and the molder is suggested to optimize these opportunities.

Concentrates

Hytrel resins should be protected from excessive temperature, UV light, and hot, moist environment.

Table 17
Concentrates*
(in a base of Hytrel 4056)

Grade	Description	Characteristics and Typical Uses
Hytrel 10MS	Hydrolytic stabilizer concentrate.	For blending with other grades of Hytrel to improve serviceability in hot, moist environments. Recommended letdown ratio is 9:1.
Hytrel 20UV	UV light stabilizer concentrate.	Used for protection of light-colored parts against UV degradation. Recommended letdown ratio is 25:1 or less.
Hytrel 30HS	Heat stabilizer concentrate.	For blending with other grades of Hytrel to retard thermal oxidative degradation and extend useful life at elevated temperatures. Recommended letdown ratio is between 16:1 and 40:1, usually about 20:1.
Hytrel 40CB	Concentrate of a fine particle size carbon black.	Hytrel must be protected against degradation from exposure to UV light when used outdoors or when exposed to sunlight. Hytrel 40CB provides the most effective protection. Recommended let-down ratio for direct outdoor exposure is 7:1.

*All concentrates are supplied in pellet form. They can be dry-blended with pellets of unmodified grades, then melt-mixed in the screw of an extruder or injection molding machine.

Hytrel 10MS

Blending with Hytrel 10MS concentrate is suggested for such products as tubing, hose, cable jackets, seals, packings, gaskets, and molded appliance parts, which require a greater degree of moisture resistance than is available with the regular types of Hytrel alone.

Hytrel 10MS is not color-stable. It is not recommended for use in light-colored or painted articles.

Table 18
Addition of Hytrel 10MS Improves Hydrolytic Stability

	Type of Hytrel							
Property	**40D**		**55D**		**63D**		**72D**	
Parts Hytrel 10MS/Parts Regular Hytrel	0/100	10/90	0/100	10/90	0/100	10/90	0/100	10/90
Final Concentration of PCD, % (by weight)	0	2	0	2	0	2	0	2
Stress/Strain Properties (Injection-Molded Slabs)								
Original								
Tensile Strength, MPa	25.5	30.2	37.9	40.5	39.3	34.3	38.8	37.4
(psi)	(3700)	(4375)	(5500)	(5875)	(5700)	(4975)	(5625)	(5425)
Elongation at Break, %	450	450	450	440	320	360	330	350
After Immersion in Water at 70°C (158°F)								
1 Month								
Tensile Strength, % of Original	66	72	Not	Not	86	95	100	100
Elongation, % of Original	107	99	Tested	Tested	103	100	118	101
3 Months								
Tensile Strength, % of Original	55	70	Not	Not	72	99	63	97
Elongation, % of Original	100	97	Tested	Tested	105	101	39	92
6 Months								
Tensile Strength, % of Original	44	64	51	82	15	92	18	93
Elongation, % of Original	39	106	71	96	2	104	1	92
9 Months								
Tensile Strength, % of Original	22	65	Not	Not	Failed	78	Failed	79
Elongation, % of Original	41	101	Tested	Tested		90		86
12 Months								
Tensile Strength, % of Original	Not	Not	43	76	—	Not	—	Not
Elongation, % of Original	Tested	Tested	69	82	—	Tested	—	Tested

Table 18
Addition of Hytrel 10MS Improves Hydrolytic Stability *(continued)*

Property	Type of Hytrel							
	40D		55D		63D		72D	
Parts Hytrel 10MS/Parts Regular Hytrel	0/100	10/90	0/100	10/90	0/100	10/90	0/100	10/90
Final Concentration of PCD, % (by weight)	0	2	0	2	0	2	0	2
Stress/Strain Properties (Injection-Molded Slabs)								
After Immersion in Water at 100°C (212°F)								
2 Weeks								
Tensile Strength, % of Original	Not Tested	Not Tested	Not Tested	Not Tested	39	92	41	94
Elongation, % of Original					3	90	2	101
1 Month								
Tensile Strength, % of Original	21	61	47	105	Failed	67	Failed	74
Elongation, % of Original	11	104	13	104		74		73
3 Months								
Tensile Strength, % of Original	Failed in 35–38 Days	47	Failed	63	—	Failed	—	Failed
Elongation, % of Original		108		90	—		—	
6 Months								
Tensile Strength, % of Original	—	14	—	62	—	—	—	—
Elongation, % of Original	—	6	—	99	—	—	—	—

Hytrel 20UV

Hytrel 20UV concentrate or other protection from UV light should be incorporated in all products of Hytrel that are used outdoors or exposed to direct sunlight via windows or reflective surfaces. In very thin parts, especially those less than 0.55 mm (0.02 in) thick, degradation due to UV radiation can be caused by exposure to incandescent or fluorescent lighting.

Hytrel 20UV blended with Hytrel may discolor with time. Where color is important, the use of pigments in combination with Hytrel 20UV is recommended. The use of pigments is discussed in the bulletin, “Pigmentation and Weathering Protection of Hytrel.”

Table 19
Hytrel 20UV Extends Serviceability of Hytrel
During Weather-ometer Exposure

Parts Hytrel 5556	100	100	100
Parts Hytrel 20UV	—	2.5	4
Letdown Ratio[a]	—	40:1	25:1
Original[b]			
Tensile Strength at Break,[c] MPa (psi)	50.8 (7375)	53.4 (7750)	41.6 (6025)
Elongation[c] at Break, %	720	750	730
Exposure Time, hr	**48**	**300**	**300**
Tensile Strength at Break, MPa (psi)		16.8 (2425)	19.8 (2875)
Elongation at Break, %		410	460
Exposure Time, hr	—	**658**	**1000**
Tensile Strength at Break, MPa (psi)	—	11.2 (1625)	10.8 (1575)
Elongation at Break, %	—	30	50

[a] Pellets dried, extrusion blended, pelletized, and dried again.
[b] Compression molded film, 0.275 mm (0.011 in) thick.
[c] Tensile and elongation measurements were carried out using a head speed of 50 mm/min (2 in/min).

Hytrel 30HS

Addition of Hytrel 30HS improves aging/thermal stability. Hytrel 5555HS is a specialty grade containing a thermal stabilizer package. Special precautions should be taken to make sure that the concentrate and Hytrel resin are dry before processing.

Hytrel 30HS is not color-stable. It is not recommended for use in light colored or painted articles.

Figure 40. Comparison of Hytrel 5556 and Hytrel 5556 Containing Hytrel 30HS with Hytrel 5555HS—Oven Aging at 121°C (250°F)

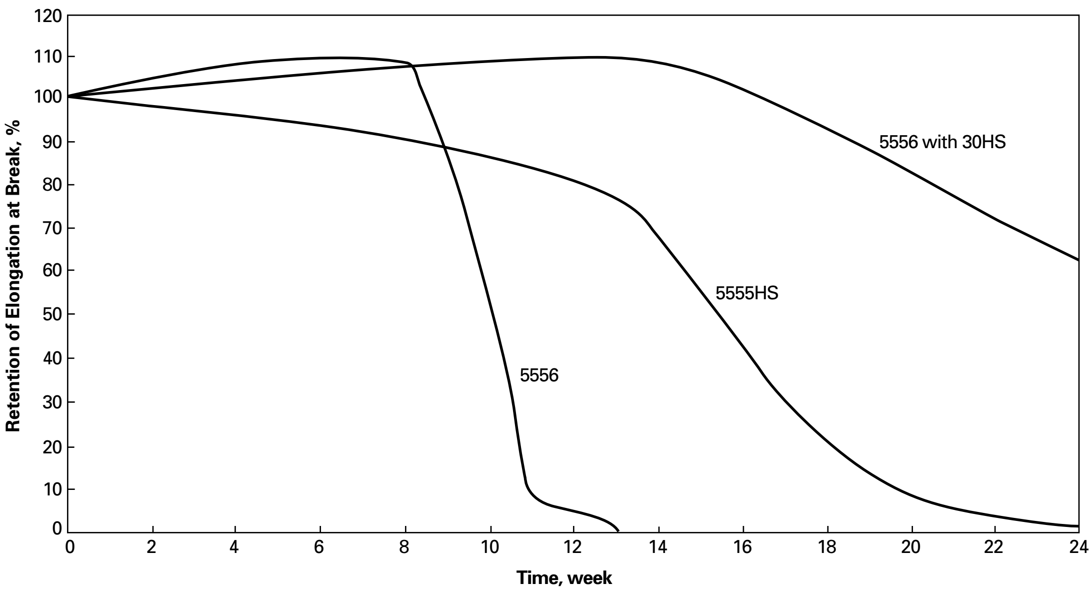


Figure 41. Comparison of Hytrel 7246 with Hytrel 7246 containing Hytrel 30HS— Oven Aging at 177°C (351°F)

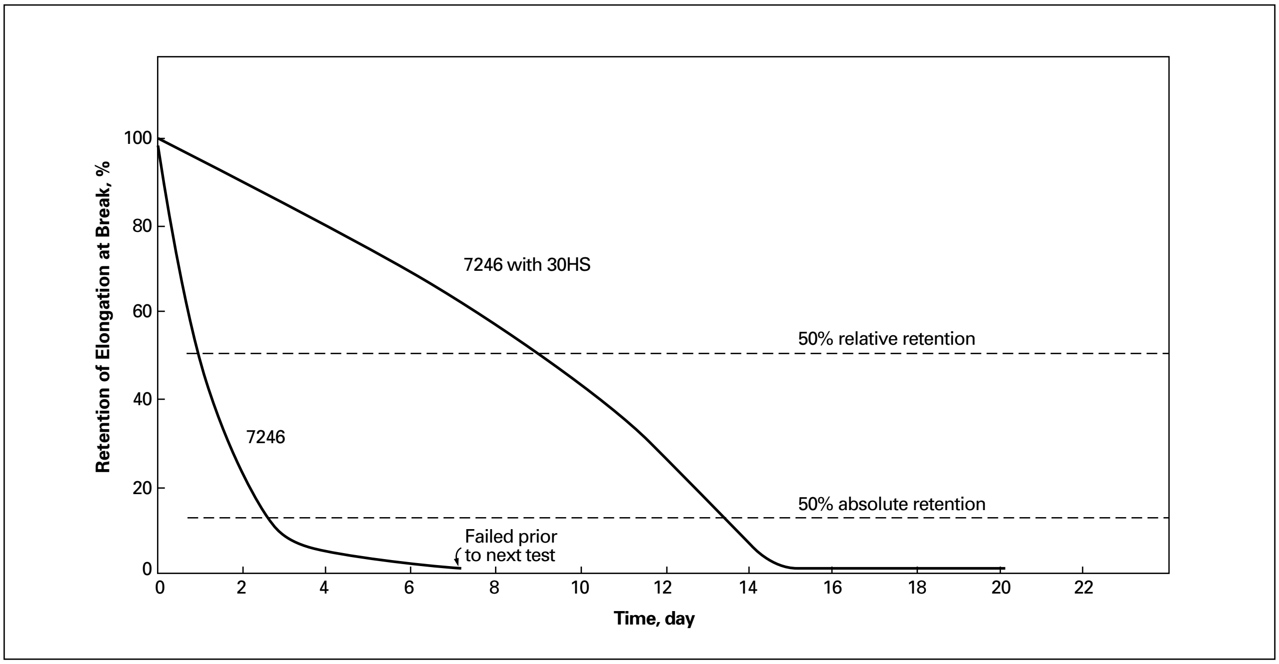
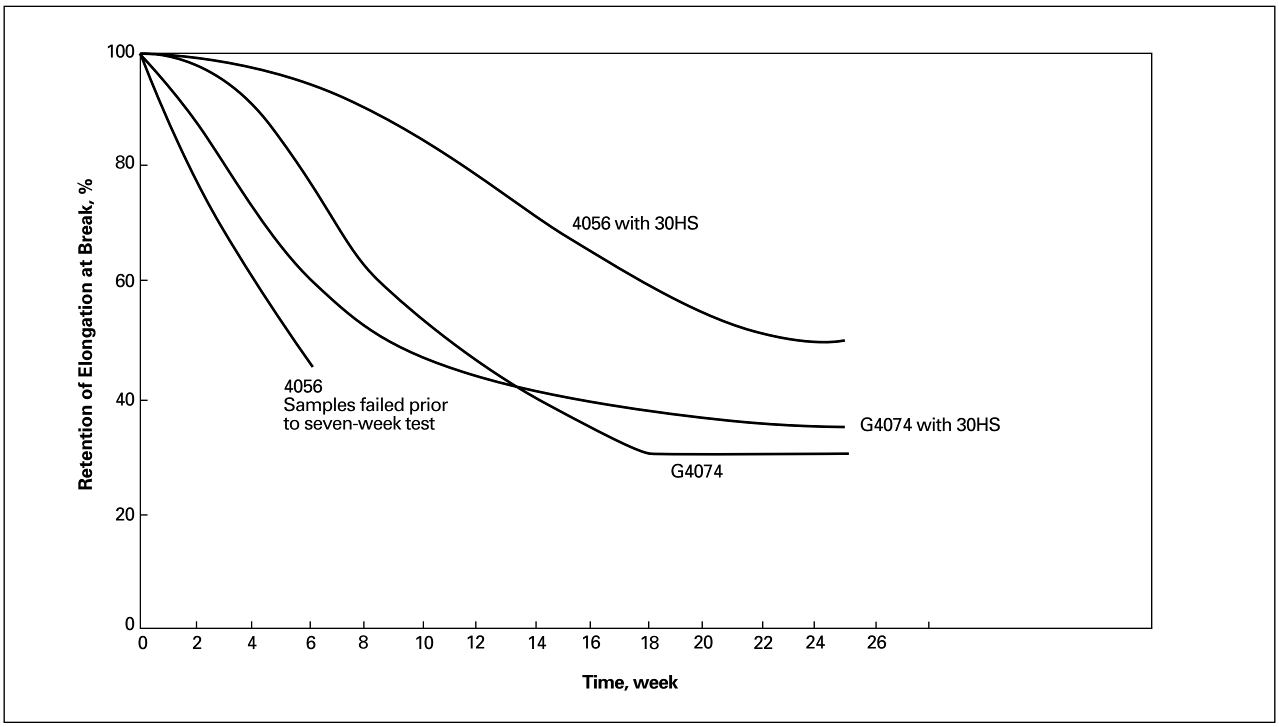


Figure 42. Comparison of Hytrel 4056 and Hytrel G4074 containing Hytrel 30HS— Oven Aging at 121°C (250°F)



Notes: All test specimens used in the oven aging were "Die C" dumbbells cut from injection molded slabs 76 mm × 127 mm × 9.5 mm (3 in × 5 in × 0.075 in). Tests were made using an Instron Tensile Tester according to ASTM D 638-82 at 50 mm/min (2 in/min) for Hytrel 5555HS, Hytrel 5556, and Hytrel 7246, and at 500 mm/min (20 in/min) for Hytrel 4056 and Hytrel G4074. A letdown ratio of 20:1 was used for all samples. The figures present data for Hytrel 30HS. Colorants or additives of any kind or processing conditions may alter some or all of these properties. The data listed here fall within the normal range of product properties, but they should not be used to establish specification limits or used alone as the basis of design.

Hytrel 40CB

Hytrel 40CB concentrate or other protection from UV light should be incorporated in all products of Hytrel that are used outdoors or exposed to direct sunlight via windows or reflective surfaces.

Also very thin parts, especially those less than 0.55 mm (0.02 in) thick, should be protected as degradation due to UV radiation can be caused by exposure to incandescent or fluorescent lighting.

Table 20
Effect of Level of Carbon Black on 0.25 mm (0.10 in) Films of Hytrel after Weathering[a]

		Hytrel 5556	
Concentrate			
Letdown Ratio (Hytrel 5556/Hytrel 40CB)	—	16:1	7:1
Total Carbon Black, %	0	1.47	3.13
Original[b]			
Tensile Strength at Break, MPa (psi)	31.4 (4550)	36.4 (5275)	38.8 (5625)
Elongation at Break, %	430	535	535
Exposure Time, hr	**50**	**50**	**50**
Tensile Strength at Break, MPa (psi)		34.8 (5050)	36.6 (5300)
Elongation at Break, %		700	725
Exposure Time, hr		**150**	**150**
Tensile Strength at Break, MPa (psi)		34.2 (4975)	33.8 (4900)
Elongation at Break, %		605	710
Exposure Time, hr		**600**	**600**
Tensile Strength at Break, MPa (psi)		16.8 (2450)	27.0 (3925)
Elongation at Break, %		335	540
Exposure Time, hr		**1000**	**1000**
Tensile Strength at Break, MPa (psi)		14.4 (2075)	15.6 (2250)
Elongation at Break, %		130	235

[a] Pellets of Hytrel 40CB and Hytrel 5556 were tumble blended and extruder melt blended prior to film preparation; film was made by compression molding; Weather-ometer Carbon Arc.

[b] Properties determined at a crosshead speed of 50.8 mm/min (2 in/min).

Table 21
Effect of Level of Carbon Black on 0.25 mm (0.10 in) Films of Hytrel Exposed in Florida[a]

		Hytrel 5556	
Concentrate			
Letdown Ratio (Hytrel 5556/Hytrel 40CB)	—	16:1	7:1
Total Carbon Black, %	0	1.47	3.13
Original[b]			
Tensile Strength at Break, MPa (psi)	31.4 (4550)	36.4 (5275)	38.8 (5625)
Elongation at Break, %	430	535	535
Exposure Time, month	**3**	**3**	**3**
Tensile Strength at Break, MPa (psi)		26.0 (3775)	30.4 (4400)
Elongation at Break, %		565	680
Exposure Time, month		**6**	**6**
Tensile Strength at Break, MPa (psi)		21.6 (3125)	25.2 (3650)
Elongation at Break, %		485	550
Exposure Time, month		**9**	**9**
Tensile Strength at Break, MPa (psi)		19.4 (2800)	23.0 (3350)
Elongation at Break, %		380	455

[a] Pellets of Hytrel 40CB and Hytrel 5556 were tumble blended and extruder melt blended prior to film preparation; film was made by compression molding; outdoor aging in Florida, 5°South.

[b] Properties determined at a crosshead speed of 50.8 mm/min (2 in/min).

Fluid Resistance

Hytrel has excellent resistance to nonpolar materials, even at elevated temperatures. Polar materials at elevated temperatures may have severe effects on Hytrel. In general, fluid resistance of Hytrel improves as the stiffness of the grade increases.

Table 22 offers some general guidelines to assist in selecting the most suitable grade of Hytrel for a specific application. More detailed product data are available and should be referred to prior to making final material selection.

For simplicity, the Hytrel products have been grouped into three hardness ranges. Their ability to meet end-use requirements is rated either very suitable, generally suitable, or not suitable.

Often, the starting point in selecting the right material is to consider the end-use environment—to what conditions will the application be exposed (e.g., temperature or chemicals).

The best heat and chemical resistance is typically provided by the hardest, stiffest Hytrel grades; whereas the softer, more flexible Hytrel grades usually provide better performance in low-temperature environments.

It is important to keep in mind that the part design must accommodate the mechanical behavior of the material selected based on the environmental conditions. In addition, physical properties, methods of assembly, and other criteria all play a part in making the best material selection for the specific application.

Table 22
Fluid Resistance

	Hardness		
	35D–40D	**45D–55D**	**63D–104R**
Mineral oils and greases, Other nonaromatic hydrocarbons	■	■	■
Benzene, toluene, other aromatic hydrocarbons, chemicals, and solvents	□	▒	■
Water, alcohols, glycols			
• ambient temperature	■	■	■
• >50°C (>122°F) with 10MS	▒	▒	▒
without 10MS	□	□	□
Acids and bases			
• diluted	▒	■	■
• concentrated	□	□	□

■ Very suitable
▒ Generally suitable
□ Not suitable

Gas Permeability

Hytrel polyester elastomers have an unusual combination of polarity, crystallinity, and morphology. As a result, they have a high degree of permeability to polar molecules, such as water, but are resistant to permeation by nonpolar hydrocarbons and refrigerant gases (see **Table 23**).

In permeability to moisture, Hytrel is comparable to the polyether-based urethanes and, therefore, is useful as a fabric coating for apparel. Its low permeability to refrigerant gases and hydrocarbons, such as propane, makes Hytrel of interest for use in refrigerant hose or in flexible hose or tubing to transmit gas for heating and cooking.

Table 23
Permeability[a] of Hytrel to Gases

Gas	Hytrel 4056	Hytrel 5556	Hytrel 6346	Hytrel 7246
Air	2.4×10^{-8}	1.8×10^{-8}	—	—
Nitrogen	1.7×10^{-8}	1.4×10^{-8}	—	—
Carbon Dioxide	3.5×10^{-7}	1.8×10^{-7}	—	—
Helium	15.7×10^{-8}	9.9×10^{-8}	—	3.2×10^{-8}
Propane	$<0.2 \times 10^{-8}$	$<0.2 \times 10^{-8}$	$<0.2 \times 10^{-8}$	—
Water[b]	3.1×10^{-5}	2.4×10^{-5}	—	—
Freon® 12 Fluorocarbon	1.4×10^{-8}	1.2×10^{-8}	1.2×10^{-8}	0.82×10^{-8}
Freon 22 Fluorocarbon	0.47×10^{-8}	0.59×10^{-8}	$<0.2 \times 10^{-8}$	—
Freon 114 Fluorocarbon	41×10^{-8}	28×10^{-8}	4.6×10^{-8}	2.7×10^{-8}

[a] Units of permeability: cm^3 (at standard temperature and pressure, STP)·mm/Pa·s·m^2 at 21.5°C and $\Delta P = 34.5$ kPa or cm^3 (at STP)·cm/atm·sec·cm^2 at 71°F and $\Delta P = 5$ psi

[b] Values obtained at 90% RH, 25°C (77°F), assuming that permeability laws hold for water.

Radiation Resistance

The increasing use of nuclear energy, for example in power plants, military areas, and medicine, places new requirements on many rubber compounds as well as other materials. Some factors of importance to market development of nuclear energy include, for example: the maximum dosage to which the material can be subjected without damaging effects, the possible use of additives to provide additional stabilization to radiation, and the effect of radiation on physical properties.

Three uncompounded grades of Hytrel polyester elastomer show excellent retention of physical properties after irradiation at 23°C (73°F) in air. (The combined effect of heat-aging or steam-aging concurrent with radiation exposure was not studied.)

Injection-molded slabs of Hytrel 4056, Hytrel 5556, and Hytrel 7246, 2 mm (0.079 in) thick, were exposed to a 1.5 MeV electron beam at Radiation Dynamics Ltd., Swindon, Wiltshire, U.K. The slabs were then tested by ASTM test methods.

For the most part, the radiation of prime interest from the standpoint of insulation damage has energy of the order of 1 MeV, which is principally gamma photons and fast neutrons. Damage is caused by collisions of this radiation with electrons and nuclei in the elastomer where the energy input from such collisions may be greater than the bond energies in the elastomer.

Most elastomers are embrittled by radiation exposure, which induces cross-links between molecules. This eventually gives a three-dimensional network, such as is seen in hard rubber or phenolic resins. A few polymers, notably butyl rubber, degrade by reversion to low-molecular-weight tars and oils.

Although upgrading changes can occur under controlled low dosage (radiation cross-linked polyolefins), long exposure normally produces degradation. Thus, the amount of change is dependent on radiation flux rate, total radiation dose, energy of radiation, chemical composition of the polymer, environment (ambient temperature, air versus inert gas, steam exposure, etc.), and the initial properties of the elastomeric compound. The amount of change is independent of the type of radiation at equal energy,* whether alpha, beta, or gamma rays, or neutrons. This is known as the equal-energy, equal-damage concept.

Table 24 summarizes the effect of radiation on three hardness grades of Hytrel. It will be seen that the exposure to 150 kJ/kg (15 Mrad) produces very little change in the properties of Hytrel.

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* R. B. Blodgett and R. G. Fisher, *IEEE Transactions on Power Apparatus and Systems,* Vol. 88, No. 5, p. 529, (May 1969).

Table 24
Stability of Hytrel Polyester Elastomer to Radiation
Electron Beam, 1.5 MeV, 23°C (73°F), 70% RH, Radiation Dosage in J/kg (rad)

	ASTM Test Method	Hytrel 4056	Hytrel 5556	Hytrel 7246
Original				
Tensile Strength, MPa (psi)	D 638	24.1 (3495)	27.2 (3945)	35.7 (5175)
Elongation at Break, %	D 638	550	390	430
100% Modulus, MPa (psi)	D 638	6.8 (985)	14.4 (2090)	22.0 (3190)
Hardness, Durometer D	D 2240	40	55	72
Exposure 5 Mrad, kJ/kg		**50**	**50**	**50**
Tensile Strength, MPa (psi)		22.8 (3305)	28.3 (4105)	36.6 (5305)
Elongation at Break, %		510	470	410
100% Modulus, MPa (psi)		7.3 (1060)	14.5 (2100)	23.6 (3420)
Hardness, Durometer D		40	55	72
Exposure 10 Mrad, kJ/kg		**100**	**100**	**100**
Tensile Strength, MPa (psi)		22.8 (3305)	28.9 (4190)	37.4 (5425)
Elongation at Break, %		500	470	370
100% Modulus, MPa (psi)		6.2 (900)	14.5 (2100)	23.9 (3465)
Hardness, Durometer D		40	55	72
Exposure 15 Mrad, kJ/kg		**150**	**150**	**150**
Tensile Strength, MPa (psi)		22.1 (3205)	30.3 (4395)	38.6 (5595)
Elongation at Break, %		490	490	390
100% Modulus, MPa (psi)		6.1 (885)	14.2 (2060)	24.6 (3565)
Hardness, Durometer D		40	55	72

Resistance to Mildew and Fungus

The resistance of a high-performance 40 durometer D hardness grade of Hytrel polyester elastomer to certain fungi was determined according to ASTM D 1924-63, using the following cultures.

Culture	Observed Growth
Aspergillus niger	None
Aspergillus flavus	None
Aspergillus versicolor	Very slight, sparse
Penicillin funiculosum	None
Pullularia pullulans	None
Trichloderma sp.	None

Samples of the same grade Hytrel were also buried for one year in Panama. Instron test results were as follows.

Original	
Durometer D Hardness	40
Tensile Strength, MPa (psi)	25.5 (3700)
Elongation at Break, %	450
100% Modulus, MPa (psi)	6.9 (1000)
300% Modulus, MPa (psi)	8.8 (1275)
Retention after 1 yr Soil Burial in Panama, %	
Durometer Hardness	98
Tensile Strength	82
Elongation at Break	82
100% Modulus	99
300% Modulus	98

The harder grades of Hytrel were not included in these tests but should show at least equivalent

Chapter 7

Agency Approvals

Contents

resistance, because they are based on the same raw materials.

Food and Drug Administration

The following grades of Hytrel meet Food and Drug Administration (FDA) guidelines for food contact use in the U.S. The stabilizer system used in these grades is in full compliance with FDA regulations.

The following grades of Hytrel may be used in compliance with the Federal Food, Drug, and Cosmetic Act, specifically:

Hytrel	Contact with Dry Bulk Food (Regulation 21CFR177.1590)	Repeated Use Contact with Fatty or Wet Food (Regulation 21CFR177.2600)
4069	√	√
4556	√	√
5526	√	√
5556	√	√
6356	√	√
7246	√	√
8238	√	√
3078	√	√
4056	√	
HTR6108	√	

Essentially all High Performance grades meet FDA guideline for bulk dry food contact use in the U.S. If the customer uses compliant additives and follows the temperature and alcohol content requirements of the application, then the application should be in compliance with the repeated use regulation.

This information, based upon our experience, is offered without charge as part of our service to customers. It is intended for use by persons having technical skill, at their own discretion and risk. We do not guarantee favorable results, and we assume no liability in connection with its use. The information is not intended as a license to operate under, or a recommendation to infringe, any patent of DuPont or others.

None of the High Productivity grades have FDA approval in the U.S.—not because of the presence of toxic extractable material, but rather because they have not been tested due to the enormous expense of extraction and animal feeding tests required by the FDA.

National Science Foundation

The following grades of Hytrel have National Science Foundation (NSF) approval: 4056, 5526, 5556, and 7246, under standards 14 and 61.

Underwriters Laboratories Recognition

Underwriters Laboratories (UL) is an independent, nonprofit testing laboratory that evaluates the safety of equipment offered for sale. Many state and local governments require that electrical appliances in the U.S. carry UL approval before they can be sold within their jurisdiction.

QMFZ2 March 3, 1993
Component -- Plastics

E I DUPONT DE NEMOURS & CO INC **E51284 (R)**
DUPONT POLYMERS, ENGINEERING POLYMERS, (A card)
TEEE RESINS, PO BOX 80713, CHESTNUT RUN
PLAZA, WILMINGTON DE 19880-0713

Mtl Deg	Col	Min Thk mm	UL94 Flame Class	RTI Elec	RTI Mech with Imp	RTI Mech w/o Imp	HWI	HAI	HVTR	D495	CTI
Thermoplastic elastomer-ether-ester, designated "Hytrel", furnished in the form of pellets.											
5555HS	NC	0.71	—	90	—	—	—	—	—	—	—
		1.47	94HB	90	85	85	4	0	0	—	—
		3.05	94HB	90	85	85	3	0	0	5	0
8238	NC	1.47	94HB	90	85	85	4	0	0	—	—
		3.05	94HB	90	85	85	3	0	0	5	0
5556, 4556	NC	0.71	—	85	—	—	—	—	—	—	—
		1.47	94HB	85	85	75	3	0	0	—	—
		3.05	94HB	85	85	80	3	0	0	5	0

Reports: June 30, 1986; June 30, 1986; November 5, 1985.

Replaces E51284A dated February 9, 1993, filed E I DuPont de Nemours & Co., Inc., DuPont Polymers, Engineering Polymers.

(Cont. on B card)

324299212 H7047 Underwriters Laboratories Inc.® D11/0019035
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QMFZ2 March 3, 1993
Component -- Plastics

E I DUPONT DE NEMOURS & CO INC **E51284 (R)**
(B—cont. from A card)

Mtl Deg	Col	Min Thk mm	UL94 Flame Class	RTI Elec	RTI Mech with Imp	RTI Mech w/o Imp	HWI	HAI	HVTR	D495	CTI
G4074	NC	0.71	—	90	—	—	—	—	—	—	—
		1.47	94HB	90	85	85	4	0	0	—	—
		3.05	94HB	90	85	85	3	0	0	5	0
G5548	NC	1.57	94HB	50	50	50	3	0	—	—	—
		3.18	94HB	50	50	50	3	0	0	6	0
4069	NC	1.56	94HB	50	50	50	4	0	—	—	—
		3.18	94HB	50	50	50	4	0	0	—	0
3078	NC	1.57	94HB	—	—	—	4	0	—	—	—
		3.21	94HB	—	—	—	3	0	0	—	0

Reports: November 5, 1984; April 30, 1990; July 14, 1987; November 5, 1984.

Replaces E51284B dated February 9, 1993, filed E I DuPont de Nemours & Co., Inc., DuPont Polymers, Engineering Polymers.

(Cont. on B1 card)

324299212 N7047 Underwriters Laboratories Inc.® D11/0019036
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QMFZ2 May 20, 1993
Component -- Plastics

E I DUPONT DE NEMOURS & CO INC **E51284 (R)**
(B1—cont. from B card)

Mtl Deg	Col	Min Thk mm	UL94 Flame Class	RTI Elec	RTI Mech with Imp	RTI Mech w/o Imp	HWI	HAI	HVTR	D495	CTI
G4778	NC	1.57	94HB	50	50	50	3	0	—	—	—
		3.18	94HB	50	50	50	2	0	0	6	0
G3548,	NC	1.57	94HB	—	—	—	3	0	—	—	—
G4078		3.17	94HB	—	—	—	2	0	0	6	0
G3548W,	NC	1.50	94HB	—	—	—	4	0	—	—	—
G4078W		3.00	94HB	—	—	—	3	0	0	6	0
G4774,	NC	1.57	94HB	—	—	—	3	0	—	—	—
G5544		3.12	94HB	—	—	—	2	0	0	6	0
4059FG,	NC	1.57	94HB	—	—	—	3	0	—	—	—
6359FG		3.05	94HB	—	—	—	3	0	0	6	0

Reports: July 14, 1987; July 14, 1987; November 5, 1984; April 30, 1990.

Replaces E51284B1 dated March 3, 1993.

(Cont. on C card)

324299212 N7047 Underwriters Laboratories Inc.® D11/0215721
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QMFZ2 March 3, 1993
Component -- Plastics

E I DUPONT DE NEMOURS & CO INC **E51284 (R)**
(C—cont. from B1 card)

Thermoplastic elastomer-ether-ester, designated "Hytrel", furnished in the form of pellets.

4056, 7246	NC	1.47	94HB	—	—	—	—	—	—	—	—
6356	NC	1.57	94HB	—	—	—	—	—	—	—	—
5526	NC	1.47	94HB	—	—	—	—	—	—	—	—
		3.18	94HB	—	—	—	2	—	—	—	—
HTR8068	NC	1.57	94V-0	—	—	—	3	0	—	—	—
	BK	1.57	94V-1	—	—	—	3	0	—	—	—
	BK	3.18	94-V0	—	—	—	1	0	2	6	1
HTR5612	NC	1.57	94HB	—	—	—	4	0	—	—	—
	BK	3.30	94HB	—	—	—	2	0	0	6	0
8238	NC	0.91	94HB	—	—	—	—	—	—	—	—

Marking: Company name and material designation on container, wrapper or molded on finished part.

Reports: January 12, 1978; January 12, 1978; November 5, 1984; March 28, 1988;
March 28, 1988; July 31, 1990.

Replaces E51284C dated February 9, 1993, filed E I DuPont de Nemours & Co., Inc., DuPont Polymers, Engineering Polymers.

(Cont. on D card)

324299212 N7047 Underwriters Laboratories Inc.® D11/0144472
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QMFZ2 March 3, 1993
Component -- Plastics

E I DUPONT DE NEMOURS & CO INC **E51284 (R)**
(D—cont. from C card)

See General Information Preceding These Recognitions.

UL94 small-scale test data does not pertain to building materials, furnishings and related contents. UL94 small-scale test data is intended solely for determining the flammability of plastic materials used in the components and parts of end-product devices and appliances, where the acceptability of the combination is determined by ULI.

Replaces E51284D dated February 9, 1993, filed E I DuPont de Nemours & Co., Inc., DuPont Polymers, Engineering Polymers.

324299212 N7047 Underwriters Laboratories Inc.® D11/0152205
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QMQS2 July 27, 1994
Component -- Flame Retardant And/Or Color Concentrates

E I DUPONT DE NEMOURS & CO INC **E63766 (R)**
DUPONT ENGINEERING POLYMERS,
CHESTNUT RUN PLAZA, PO BOX 80713,
WILMINGTON DE 19880-0713
(A card)

Concentrate Dsg	Base Resin Manufacturer	Mtl Dsg	LD Col	Min Thk In.	(mm)	Minimum Let-Down Ratio	UL94 Flame Class
Flame retardant concentrates, furnished in the pellet form, for use in the specified Recognized thermoplastic elastomer-ether-ester resins shown below.							
Hytrel 50FR	DuPont	Hytrel 4056	NC	0.062	(1.57)	1:6.7	94V-2
Hytrel 50FR	DuPont	Hytrel 5526	NC	0.063	(1.60)	1:10	94V-2
Hytrel 50FR	DuPont	Hytrel 7246	NC	0.066	(1.67)	1:10	94V-2
Hytrel 51FR	DuPont	Hytrel 4056	NC	0.06	(1.52)	1:10	94V-2
Hytrel 52FR	DuPont	Hytrel 5555HS	NC	0.06	(1.52)	1:10	94V-2
Hytrel 52FR	DuPont	Hytrel 5556	NC	0.06	(1.52)	1:10	94V-2
Hytrel 52FR	DuPont	Hytrel 7246	NC	0.12	(3.00)	1:10	94V-2
Hytrel 52FR	DuPont	Hytrel 8238	NC	0.06	(1.52)	1:10	94V-2

Report: January 12, 1978.

Replaces E63766A dated February 9, 1993.

(Cont. on B card)

324299182 H3082 Underwriters Laboratories Inc.® D11/0010940
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Chapter 8

Applications

Contents

The UL listing cards for Hytrel base resins and compositions with 51FR and 52FR flame-retardant concentrates are attached.

General Considerations

The following general stepwise procedure is intended to help minimize problems during the growth of a design and to aid in the rapid development of a successful commercial product.

As an initial step, the designer should list the anticipated conditions of use and the performance requirements of the article to be designed. He/she may then determine the limiting design factors and, by doing so realistically, avoid pitfalls that can cause loss of time and expense at later stages of development. Use of the checklist (below) will be helpful in defining design factors.

Design Checklist

General Information
- What is the function of the part?
- How does the assembly operate?
- Can the assembly be simplified by using Hytrel?
- Can it be made and assembled more economically?
- What tolerances are necessary?
- Can a number of functions be combined in a single molding to eliminate future assembly operations and simplify design?
- What space limitations exist?
- What service life is required?
- Is wear resistance required?
- Can weight be saved?
- Is light weight desirable?
- Are there acceptance codes and specifications such as SAE or UL?
- Do analogous applications exist?

Structural Considerations
- How is the part stressed in service?
- What is the magnitude of stress?
- What is the stress versus time relationship?
- How much deflection can be tolerated in service?

Environment
- Operating temperature?
- Chemicals, solvents?
- Humidity?
- Service life in the environment?

Appearance
- Style?
- Shape?
- Color?
- Surface finish?
- Decoration?

Economic Factors
- Cost of present part?
- Cost estimate of Hytrel part?
- Are faster assemblies and elimination of finishing operations possible?
- Will redesign of the part simplify the assembled product and thus give rise to savings in installed cost?

Manufacturing Options
- Should the proposed design be machined, blow molded, melt cast, injection molded, or extruded considering the number of parts to be made, design geometry, and tolerances?
- If injection molding is chosen, how can mold design contribute to part design?
- In subsequent assembly operations, can the properties of the chosen material be used further (e.g., spin welding, snap fits)?
- After preliminary study, several steps remain to convert design ideas into production.

Drafting the Preliminary Design

After considering end-use requirements, the designer is ready to define the part geometry. This may be done in several stages with preliminary drawings indicating the basic design and functions. More detailed sketches provide information on thickness, radii, and other structures, as worked out from end-use considerations.

Prototyping the Design

Prototypes can be prepared by several techniques. A common approach is to machine the part from rod or slab stock (see the “Machining Hytrel” bulletin). If machining operations are expected to be elaborate or expensive, it is sometimes advisable to x-ray the part to avoid using material with voids. A medical type unit will show voids as small as 1.58 mm (0.0625 in) diameter, and even greater resolution can be obtained with some industrial units.

The melt stability of Hytrel permits production of prototypes by melt casting, which is a process using an extruder to fill an inexpensive aluminum mold. This method can also be advantageous for short production runs because setup costs are low. For further information, see the “Melt Casting” bulletin.

In any large and important development, the preparation of prototypes, using the fabrication method intended for production, can provide added assurance against failure in use. For injection-molded parts, the use of an inexpensive aluminum, brass, or copper beryllium mold is frequently considered an important step between conception and production. In addition, molded prototypes provide information on gate location and on mold shrinkage.

Additional reasons why the molded prototype is preferred to the machined prototype are:

- Machine marks may result in variable behavior.
- Orientation effects in the molded parts resulting from gate location or knockout pins may influence toughness.

Testing the Design

Every design should be subjected to some form of testing while in the prototype stage to check the accuracy of calculations and basic assumptions.

- Actual end-use testing of a part in service is the most meaningful kind of prototype testing. Here, all of the performance requirements are encountered, and a complete assessment of the design can be made.
- Simulated service tests are often conducted with prototype parts. The value of this type of testing depends on how closely the end-use conditions are duplicated. For example, an automobile engine part might be given temperature, vibration, and hydrocarbon resistance tests; a luggage fixture could be subjected to impact and abrasion tests; and a radio component might undergo tests for electrical and thermal insulation.
- Standard test procedures, such as those developed by the ASTM, generally are useful as a design guide but normally cannot be drawn upon to predict accurately the performance of a part in service. Again, representative field testing may be indispensable.

Long-term performance must sometimes be predicted on the basis of “severe” short-term tests. This form of accelerated testing is widely used but should be used with discretion, because the relationship between the long-term service and the accelerated condition is not always known.

Taking a Second Look

A second look at the design helps to answer the basic question: “Will the product do the right job at the right price?” Even at this point, most products can be improved by redesigning for production economies or for important functional and aesthetic changes. Weak sections can be strengthened, new features added, and colors changed. Substantial and vital changes in design may necessitate complete evaluation of the new design. If the design has held up under this close scrutiny, specifications then details of production can be established.

Writing Meaningful Specifications

The purpose of a specification is to eliminate any variations in the product that would prevent it from satisfying the functional, aesthetic, or economic requirements. The specification is a complete set of written requirements that the part must meet. It should include such things as: generic name, brand and grade of material, finish, parting line location, flash, gating, locations where voids are intolerable, warpage, color, and decorating and performance specifications.

Setting Up Production

Once the specifications have been carefully and realistically written, molds can be designed and built to fit the processing equipment. Tool design for injection molding should be left to a specialist or able consultant in the field, because inefficient and unnecessarily expensive production can result from improper design of tools or selection of manufacturing equipment.

Controlling the Quality

It is good inspection practice to schedule regular checking of production parts against a given standard. An inspection checklist should include all the items that are pertinent to satisfactory performance of the part in actual service at its assembled cost. The end user and molder should jointly establish the quality control procedures that will facilitate production of parts within specifications. (See DuPont Engineering Polymers, Module I, for general design principles.)

Design Methods

Using Physical Property Data

The designer who is new to Hytrel polyester elastomer and plastics can rely on much of his/her background with other materials (such as metals) to form a basis for design analysis and synthesis of a molded or extruded part of Hytrel. Two basic areas that must be considered most carefully are property data and effect of environment.

Whereas property data in this book are presented in the same fashion as for metals, the use of the data in conventional engineering design formulas can vary. For example, the stress-strain relationship is not linear below the yield point and does change with time under load. A single number cannot be used for modulus as is done with metals. For short-term loading, the stress-strain curves can be consulted for the secant modulus at a particular load and temperature. The secant modulus is then substituted for elastic modulus in the appropriate equation. In applications involving long-term loading, the creep modulus curves must be used to estimate the modulus at a given point in time. This procedure is illustrated by the following example:

Problem: A part design calls for a 135 N load to be suspended from the center of a beam 25 mm tall, 6.5 mm thick, and 165 mm long supported at its ends. The part specification requires that the beam not sag more than 15 mm after 30 days continuous loading. The designer wishes to use Hytrel 6356 for this part. Will it meet the sag requirement?

Solution: The first step is to calculate the stress level in the part. The maximum stress occurs in the outermost fibers and is calculated by the following equation:

$$\sigma = \frac{MZ}{I}$$

where σ = stress in outer fibers
M = bending moment
Z = distance from neutral axis
I = moment of inertia

Calculating the bending moment:

$$M = \frac{Fl}{4}$$

where F = load
l = length of beam between supports

Therefore,
$$M = \frac{(135)(165)}{4}$$
$$= 5569 \text{ N·mm}$$

For a rectangular cross section of base (b, mm) and height (h, mm):

$$I = \frac{bh^3}{12} = \frac{(6.5)(25)^3}{12}$$
$$= 8464 \text{ mm}^4$$

Finally, calculating the stress,

$$\sigma = \frac{(5569)(12.5)}{8464}$$
$$= 8.22 \text{ MPa}$$

Referring to **Figure 23**, the modulus for Hytrel 6356 at a stress level of 8.22 MPa after 30 days is approximately 126 MPa.

Using the appropriate equation to calculate deflection:

$$Y_{max.} = \frac{Fl^3}{48\,El}$$

where $Y_{max.}$ = deflection at center of beam
E = Young's modulus. In this case, the modulus determined from **Figure 23** is to be used.

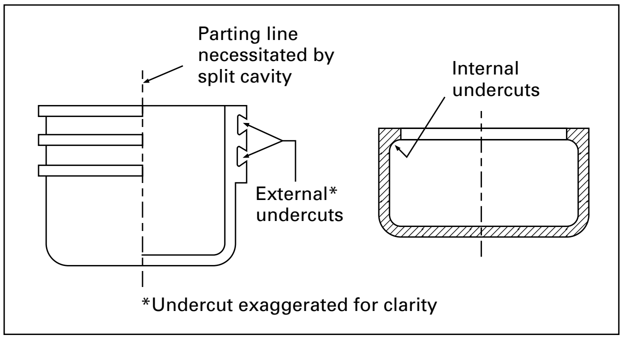
Therefore,
$$Y_{max.} = \frac{(135)(165)^3}{48(126)(8464)}$$
$$= 11.8 \text{ mm}$$

Hytrel 6356 will meet the requirements of the application.

Undercuts

Undercuts, classified as internal and external, are molded in parts for functional reasons or for decoration. Undercuts may increase tooling costs and lengthen cycles, but this is dependent on the type and location of the undercuts on the part. Undercuts are formed by using split cavity molds and collapsible cores and stripping the part from core or cavity (see **Figure 43**).

Figure 43. Types of Undercut



The allowable undercut will vary with type of Hytrel, wall thickness, and diameter. The undercut should be well rounded and filleted to allow for easy removal of the part from the mold and to minimize stress concentrations during stripping.

Also, the undercut part must be free to stretch or compress; that is, the wall of the part opposite the undercut must clear the mold or core before ejection is attempted. Adequate part contact area should be provided during stripping so that penetration of the part does not occur by the knock-out system or the wall does not collapse.

Realistic Tolerances

One of the most important steps in the design of gears is the specification of realistic tolerances. Plastic gears do not require the high tolerances of metal gears. The best tolerances that can normally be met with injection-molded gears are in the range of AGMA Quality No. 5, 6, 7. This means that total composite error may be held between 0.08 and 0.13 mm (0.003 and 0.005 in), with tooth-to-tooth composite error between 0.03 and 0.05 mm (0.001 and 0.002 in).

Closer tolerances can be held in an injection-molded gear, but the designer must expect to pay a premium because higher tooling cost, fine control of the molding conditions, and close inspection of the gears usually will be required.

Assembly

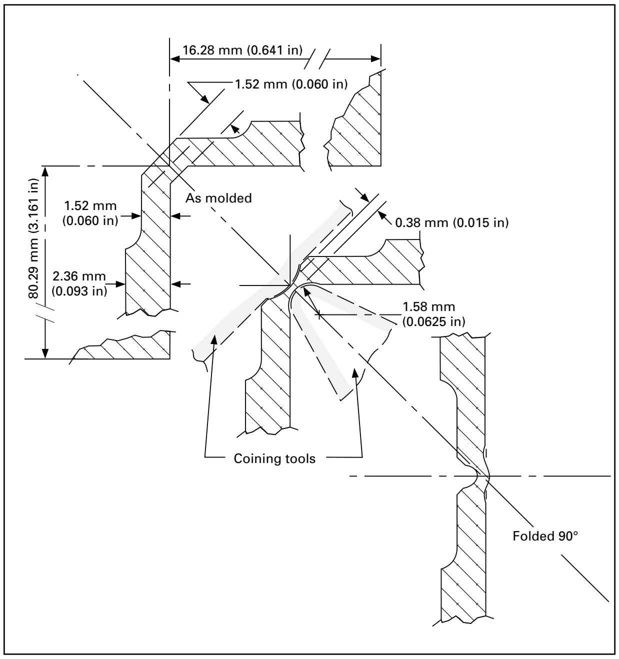
A Coined Hinge

Coining can be used as an assembly method. In **Figure 44**, a housing is coined near the cover portion so that it can be permanently closed and sealed. The advantage of the coining method is that the coined section, though only 25% the thickness of the adjoining walls, has an equivalent strength. This would not be true were the hinge area molded with a 0.38 mm (15 mil) wall.

Designing for Ultrasonic Assembly

Sonic welding is a satisfactory way to assemble parts fabricated from the harder types of Hytrel. The design in **Figure 45** for an automotive valve component is a good example. The step joint is placed on the exterior of the lower part. The web of the lower part will then retain or support the diameter of the weld surface, and the mating weld surface on the upper part can be retained by an encircling fixture. This overcomes the possibility of the weld surface on the upper part distorting inwardly. This distortion, of course, could affect the weld strength. Make the axial length of the upper weld surface 2.03 mm (0.080 in) greater than the axial length of the lower weld surface 1.9 mm (0.075 in) to ensure that the parts will bottom out on the welding line.

Figure 44. A Coined Hinge



Designing for Vibration/Weld Assembly

For rigid parts with a large weld area, the preferred assembly method is vibration welding. As an example, the carbon cannister used for automotive fuel vapor emission control is an ideal candidate. Because it is rectangular, spin welding is not practical; its large weld area precludes the use of sonic welding because of the need for a high energy source, and a hermetic seal is required. The type of vibration weld used in **Figure 46** is linear, the cover plate and body moving relative to each other along an axis down the long centerline of the open end of the body. The flange that forms the weld surface is ribbed to maintain proper flatness during the welding operation. Note the clearance allowed between the recessed portion of the cover and the inside of the body.

Figure 45. Designing for Ultrasonic Assembly (Automotive Valve Component)

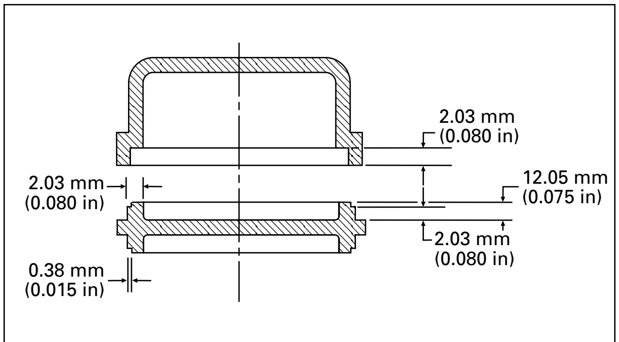
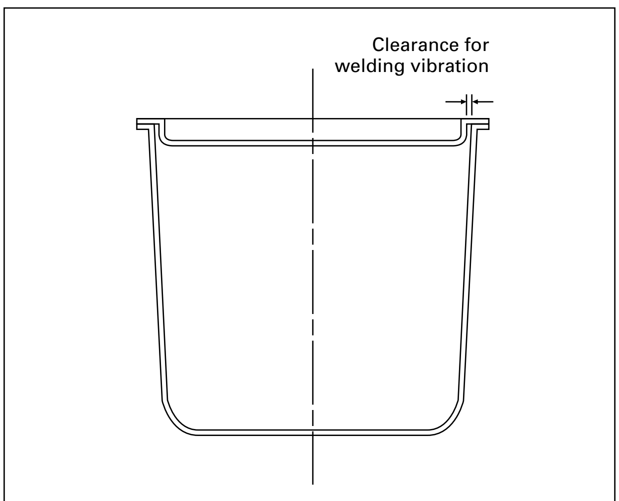


Figure 46. Design for Vibration Weld Assembly



Assembly Techniques

Bonding of Hytrel to Metal

1. Grit-blast the metal surface using clean, sharp, 90-mesh aluminum oxide grit.
2. Degrease the grit-blasted surface with toluene or methyl ethyl ketone. Use a clean, lint-free cloth.
3. Brush-apply a thin coat of Chemlok AP-134 adhesion promoter as soon as possible after grit-blasting and degreasing. Allow the coat to dry for 40 min at room temperature. The dry film should be no more than 25 µm (1 mil) thick; heavier coats will reduce bond strength.
4. Brush-apply a coat of mixed Tycel primer (100 parts Tycel 7000 adhesive with 5 parts Tycel 7203 curing agent—pot life, 12 hr). Allow the primer coat to dry 30 min at room temperature. The dry primer film should be approximately 50 µm (2 mil) thick; total adhesion promoter + primer film thickness = 75 µm (3 mil).
5. Protect cleaned and primed surfaces from contamination by dirt, oil, or grease during storage.
6. Injection-mold Hytrel onto the primed surface using a normal molding cycle. (See the bulletin, "Injection Molding," for standard injection molding conditions.)
   a. For optimum bond strength, molding must be done within 2.5 hr after priming.
   b. Preheating of the metal insert is not necessary if the substrate is steel. However, some increase in bond strength to aluminum can be achieved by preheating the insert to 190°C (375°F).

Preparation of Metal Surface

Proper preparation of the metal surface is very important, because any trace of oil, grease, moisture, or oxide film will reduce adhesion. Proper preparation consists of grit-blasting and degreasing, followed by priming. Degreasing must be done *after* grit-blasting, because the grit may be contaminated with oil. Avoid using fast-evaporating solvents (e.g., acetone or methylene chloride) to degrease; they can cause moisture to condense on the metal surface when they evaporate.

Adhesion will not be obtained unless the clean surface is primed. Grit-blasting and degreasing alone are not sufficient preparation.

Primer System

One primer system that produces acceptable bond strength is a coat of Chemlok[1] AP-134 primer, followed by a coat of Tycel 7000/Tycel 7203 adhesive. Use of Chemlok AP-134 as an adhesive promoter yields a substantial increase in bond strength compared to that obtained with the Tycel 7000/Tycel 7203 system alone (see **Table 26**).

Thixon[2] 406 bonding agent can also be used as a primer system, but good bond strength is achieved only if the metal insert is preheated within a specific temperature range (**Table 25**).

Open Time

Open time is the time period between application of the primer and use of the primed insert in the injection molding operation. For optimum bond strength, open time should be no more than 2.5 hr. Bond strength is reduced considerably at longer open times (see **Table 25**). If open time exceeds 4 hr, there will be essentially no adhesion between Hytrel and the metal insert.

Table 25
Effect of Open Time on Bond Strength

Open Time, hr*	Bond Strength (90° peel), kN/m (lb/in)
1.0	5.2 (30)
1.5	8.8 (50)
2.0	7.9 (45)
2.5	8.4 (48)
3.0	5.2 (30)
3.5	4.9 (28)
4.0	1.8 (10)
16.0	0 (0)

Notes: Same bonding procedure
Primer system—Chemlok AP-134 plus Tycel 7000/7203
Substrate temperature: 24°C (75°F)
Polymer—55D Hytrel
Standard injection molding conditions for 55D Hytrel
Bonds aged 5 days at 24°C (75°F) before testing

[1] Chemlok is a trademark of Lord Corporation.

[2] Thixon is a trademark of Morton International

Note: Before processing Hytrel polyester elastomer, read the bulletin, "Handling and Processing Precautions for Hytrel."

Substrate Type and Temperature

Workable levels of adhesion can be obtained in bonding Hytrel to tool steel, stainless steel, aluminum, and brass, using the specified primer system (see **Tables 26** and **27**). With a steel insert, no increase in bond strength is achieved by heating the substrate; with an aluminum insert, however, some benefit is gained by preheating to 190°C (375°F).

Type of Hytrel

All types of Hytrel polyester elastomer can be bonded to a variety of substrates using the procedure and primer system shown (**Table 27**). Bond strength tends to be greater for the lower hardness polymers and decreases slightly as polymer hardness increases.

Table 26
Effect of Primer and Substrate Temperature on Bond Strength

Substrate	Primer System	Substrate Temperature, °C (°F)	Bond Strength (90° peel), kN/m (lb/in)
Steel	Tycel 7000/7203 with Chemlok AP-134 primer	24 (75) 121 (250) 190 (375)	8.2 (47) 7.7 (44) 8.4 (48)
Steel	Tycel 7000/7203 alone	24 (75) 121 (250) 190 (375)	3.5 (20) 2.6 (15) 3.3 (19)
Steel	Thixon 406	24 (75) 121 (250) 190 (375)	0.2 (1) 7.9 (45) 0 (0)
Aluminum	Tycel 7000/7203 with Chemlok AP-134 primer	24 (75) 121 (250) 190 (375)	6.0 (34) 6.1 (35) 7.7 (44)
Aluminum	Tycel 7000/7203 alone	24 (75) 121 (250) 190 (375)	3.0 (17) 3.0 (17) 7.7 (44)

Notes: Same bonding procedure except for the primer system
Open time—less than 1.5 hr
Polymer—55D Hytrel; thickness—3.2 mm (0.125 in)
Standard injection molding conditions for 55D Hytrel
Bonds aged 5 days at 24°C (75°F) before testing

Table 27
Effect of Polymer and Metal Type on Bond Strength

Polymer	Substrate	Bond Strength (90° peel), kN/m (lb/in)
40D Hytrel	Steel	12.8 (73)
	Aluminum	8.1 (46)
	Brass	14.7 (84)
	Stainless Steel	14.9 (85)
55D Hytrel	Steel	9.6 (55)
	Aluminum	7.0 (40)
	Brass	12.3 (70)
	Stainless Steel	11.4 (65)
63D Hytrel	Steel	5.1 (29)
	Aluminum	5.2 (30)
	Brass	8.8 (50)
	Stainless Steel	9.5 (54)
72D Hytrel	Steel	5.2 (30)
	Aluminum	2.3 (13)
	Brass	7.9 (45)
	Stainless Steel	7.9 (45)

Notes: Same bonding procedure
Primer System—Chemlok AP-134 plus Tycel 7000/7203
Open time—less than 1.5 hr
Substrate temperature: 24°C (75°F)
Standard injection molding conditions for the various types of Hytrel
Bonds aged 5 days at 24°C (75°F) before testing

Bonding During Compression Molding or Melt Casting

Considerably stronger bonds between Hytrel and metal can be achieved during compression molding or metal casting than during injection molding, because a substantially longer contact time under heat and pressure is inherent in these operations.

Procedure for Bonding Hytrel to Metal During Compression Molding or Melt Casting

1. Grit-blast the metal surface using clean, sharp, 90-mesh aluminum oxide grit.
2. Degrease the grit-blasted surface with toluene or methyl ethyl ketone. Use a clean, lint-free cloth.
3. Brush-apply a prime coat of Thixon 406 bonding agent as soon as possible after grit-blasting and degreasing. Allow the coat to dry for 30 min at room temperature. The dry coating should be approximately 25 µm (1 mil) thick; heavier coats will reduce bond strength.
4. If desired, brush-apply a second coat of Thixon bonding agent and allow it to dry for 30 min at room temperature.
5. Protect cleaned and primed surface from contamination by oil, grease, and mold lubricants during storage.
6. Preheat metal to molding temperature if desired (see text).
7. Melt cast or compression mold Hytrel onto the primed metal, using standard techniques for these operations.

Preparation of Metal Surface

The same precautions cited in the discussion of preparation of metal surfaces for bonding during injection molding apply to the compression molding and melt casting operations as well. The metal surface must first be grit-blasted and degreased to remove all traces of oil, grease, or oxide film, and then must be primed with a commercial adhesive bonding agent.

Primer System

Thixon 406 bonding agent gives excellent adhesion between 55D Hytrel and heated or unheated brass or steel, producing bond strength in excess of 87.5 kN/m (500 lb/in), see **Table 28.** It should also be satisfactory for use with other types of Hytrel polyester elastomer.

A two-part curing system of Thixon bonding agents 403 and 404 can also be used, but it produces lower bond strength than the preferred primer.

Substrate Type and Temperature

Excellent adhesion between Hytrel and brass or steel is obtained with the bonding agents cited (**Table 28**). Although no data are shown, adhesion to other metals should also be satisfactory if the preferred primer is used.

Pressure on the Melt

Slightly better adhesion is obtained if pressure is applied to the polymer melt, as in compression molding. Applied pressure probably produces more intimate contact between the melt and the primed surface.

Table 28
Bonding 55D Hytrel to Brass and Steel

Substrate	No. of Prime Coats	Substrate Temperature, °C (°F)	Bond Strength (90° peel), kN/m (lb/in)
Steel	1	24 (75)	87.5 (500)
Steel	2	24 (75)	87.5 (500)
Steel	1	204 (400)	92.8 (530)
Steel	2	204 (400)	91.0 (520)
Brass	1	24 (75)	103.2 (590)
Brass	2	24 (75)	101.5 (580)
Brass	1	204 (400)	87.5 (500)
Brass	2	204 (400)	101.5 (580)

Notes: See procedure for bonding Hytrel to metal during compression molding or melt casting.
Primer—Thixon 406

Welding

Hytrel, being a thermoplastic material, may be welded to itself and to some other plastics by most conventional plastic welding techniques.

Each of these has certain advantages, and the choice depends on such things as: size/shape of parts, shape and type of joint required, grade of Hytrel, and equipment available. This information covers five basic welding methods and describes the applications that are appropriate in each case. These are:

- Hot plate/hot knife method
- Sheet welding by hot air and other methods
  - Hot air
  - Hot air and hot melt extrusion
  - Hot wedge
- High frequency welding
  - Dielectric heating
  - Inductive heating
- Ultrasonics
- Spin/friction welding
- Welding to other thermoplastics

Hot Plate/Hot Knife Method

This method is simple to operate and suitable for welding many Hytrel items, particularly injection molded parts and solid section profiles (e.g., V-belts).

"Hot plate" welding is the term generally applied to the technique used with injection molded parts, where the two halves are brought into contact with a heated plate (flat or profiled) until both surfaces have been melted. The components are then removed from contact with the plates and quickly brought together at a preset pressure for several seconds until the joint has set.

All grades of Hytrel may be used for hot plate welding; however, it may be difficult to achieve a good weld with blow molding grades such as HTR4275. This is because the low melt flow makes it more difficult for the two melted surfaces to flow together. If this problem occurs, higher temperatures (up to 280°C [536°F]) may help.

"Hot knife" refers to the type of tool used for welding small solid profiles such as V-belts. Otherwise the principle is the same.

For successful welding, it is important to ensure the following:

- Plate surface temperature 20–50° above melting point of the Hytrel, depending on grade.
- Best results obtained with nonstick plate surface (e.g., use self-adhesive PTFE/glass fiber tape).
- Holding pressure should be *low* during melting stage, then higher pressure is required when making the joint.
- Parts should be lined up accurately. Melting and application of pressure must be uniform around the joint.
- Joint design should provide for flow of material from the weld line.

Sheet Welding by Hot Air

This method can be used for welding and heat sealing Hytrel sheeting in applications such as tank and pit liners (typical sheeting thicknesses 0.5 to 1.5 mm [0.02 to 0.06 in]). A handheld electric blower provides a temperature-controlled jet of hot air through a specially shaped flat nozzle that is moved along slowly between the overlapping sheet edges. The inside surfaces of both sheets of Hytrel are melted and then forced together by a rubber hand roller that is applied along the top of the joint about 10 cm (25.4 in) behind the nozzle.

Advantage

Equipment is relatively inexpensive and lightweight. It is convenient to use for field (i.e., on-site) weld-ing inside tanks and other places where factory prefabrication of all joints is not possible.

Disadvantages

- Difficult to achieve consistent, reliable results. Success depends on the skill of the operator.
- Sensitive to temperature changes—insufficient heat will not melt the surfaces, while too much heat may cause blow holes, etc.
- Only suitable for certain grades of Hytrel, such as 4056, G4075, 5556. Very high or very low melt flow grades (e.g., 5526 and HTR4275), as well as those with additives such as 10MS, have been found to be difficult to weld by this method.

Welding with Hot Air Combined with Hot Melt Extrusion

A modification of the above method is to apply a molten bead of Hytrel to the joint area, combined with hot air preheating of the sheet surfaces, followed by hand roller pressure. Good welds have been produced using this equipment with several grades of Hytrel sheeting, including those containing 10MS.

Hot Wedge

This technique uses a seam welding machine that contains an electrically heated wedge, which is passed between the two sheet edges to be joined. The handheld machine is moved along by two powered rollers, which also press the sheeting together behind the wedge. A device of this type has been successfully used for factory prefabrication of Hytrel sheeting for tank liners.

High Frequency (HF) Welding

Dielectric Heating

This method can generally only be applied to sheet welding (up to 1.5 mm [0.06 in]) but is very suitable for factory (i.e., prefabrication) welding of nozzles and similar areas for tank linings. The principle of this method is that the material to be welded becomes the dielectric between two capacitor plates (formed by the steel work table and the metal electrode), which are part of a high-frequency AC circuit. The frequency used is allocated by law and in most cases is 27.12 MHz. When the circuit is energized, heat is generated in the dielectric material; the amount of heat is dependent on:

- Frequency used (usually fixed by law and by machine manufacturers).
- Voltage applied—this is the normal means of controlling the power available for heat generation in the weld, after other parameters have been established. However, excessive voltage can cause dielectric breakdown of the material, resulting in “burn holes.”
- Electrode area—the bigger the area, the more power is required from the machine, all other conditions being equal. The electrode, and hence the weld area, is therefore limited by the capacity of the machine. For Hytrel, which has a lower dielectric loss than other plastics, the optimum electrode area for a 1.5 kW machine is about 150 mm × 12 mm (5.9 in × 0.5 in) (i.e., 1800 mm^2 [2.95 in^2]).
- Thickness of material to be welded—the maximum sheet thickness that can be easily welded with a 1.5 kW machine is approximately 1.5 mm (0.06 in).
- Type of material—materials with low dielectric loss factors, such as Hytrel, require higher voltage or smaller electrodes than other materials such as PVC.
- Loss—the loss of heat from the joint by conduction through the metal electrodes. It is advantageous (see below) to cover the work table and electrode with heat-insulating material (which may itself act as a dielectric and generate heat). Another technique is to use an electrically-heated electrode.
- Time—the temperature reached in the weld area will rise over several seconds until an equilibrium is reached where heat energy being generated is equal to heat losses (conduction, radiation, etc.). If the power applied by the machine is not sufficient, then this equilibrium temperature will be below the melting point of the material, and no weld is possible. Provided sufficient power is available, the operator then determines when welding has occurred (by visual indication of the joint area and power meter) and switches off the power. This time varies between 3 and 8 sec depending on the grade of Hytrel, thickness, etc.

For successful welding of Hytrel by this method, the following points are also important:

- A heated (temperature-controlled) electrode is best for consistent results, because the power setting required for a particular material type and thickness depends on the electrode temperature. A heated electrode reduces heat conduction from the joint and eliminates variability caused by a cold electrode, which warms as it is used.

- Heat generation at the joint can be assisted by use of a thin paper/Mylar® laminate—known as “elephant hide”—on top of the work table. An additional layer of varnished cloth under the elephant hide has been used to further increase the heat. Also, a self-adhesive PTFE tape over the electrode surface can be used for similar reasons, although this should not be necessary with a heated electrode.
- Where possible, the joint line should fall approximately midway between the electrode and the work table, i.e., use two sheets of equal thickness. This way the surfaces to be welded are at the point where maximum heat is generated.

The 40D and 55D grades have been very successfully welded by this method. Harder grades of Hytrel sheet up to 1 mm (0.04 in) may be welded, but longer times may be required.

Inductive (Electromagnetic) Welding

This technique is based on the principle that heat can be induced in certain materials by alternating electromagnetic fields. The most effective result is obtained when a magnetic material is subjected to a high-frequency field produced by an **induction generator** via water-cooled **work coils**. The frequency is normally determined by legally established values in the range of 4–40 MHz.

For welding applications, the magnetic material takes the form of fine metal, graphite, or ferrite particles that are dispersed in a tape or rod of the material to be welded. This tape is then positioned in the joint area, and by action of the applied electromagnetic field and external pressure, the tape material fuses with the two surfaces to form a welded joint.

This method can be applied to sheeting applications as well as to injection molded or other parts, as long as the geometry of the weld line will allow coils to be placed so as to provide a magnetic field of sufficient intensity to melt the weld material.

Ultrasonic Welding

Ultrasonic energy is transmitted to thermoplastics, in the form of high-frequency mechanical vibrations that cause the areas in contact to melt by frictional heat and to fuse together, producing a high-strength joint.

A power supply converts a line voltage of 50–60 Hz to an ultrasonic frequency, generally 20 kHz. A transducer then converts the 20 kHz electrical energy to mechanical energy of the same frequency. The horn (metal tool that contacts the work) transmits the mechanical vibrations of the transducer to the parts being assembled. Hytrel has been successfully welded using ultrasonics; however, the rate of welding is slower than for other methods because the contact area of the horn is relatively small.

The following considerations are important in determining the applicability of this method to Hytrel.

- The more rigid plastics are easier to weld. Hytrel requires high-power input because of its flexibility.
- The higher the modulus, coefficient of friction, and thermal conductivity, the easier it is to weld.
- The lower the melt temperature, density, and specific heat, the easier it is to weld.
- Mold release agents and lubricants can reduce frictional heating and must be removed.
- If different grades of Hytrel are being assembled, the melting points of these grades should differ by no more than 10–15°C (18–27°F).

Spin/Friction Welding

Friction welding is generally considered to mean rotary or spin welding, where one part is rotated at high speed against the other while a steady pressure is applied. Frictional heat develops at the surface, and when a prescribed amount of melt is developed, rotation is stopped while pressure is maintained on the joint until the bond has solidified.

Basic variables of spin welding are rotational speed, joint pressure, and spin time. If two different Hytrel grades having differing melting points are to be assembled by this process, these variables must be adjusted such that *both* polymer surfaces are melted.

A limitation of the spin welding technique is the difficulty in using it for very flexible polymers or thin cross sections. Spinning parts of these flexible materials under pressure will cause distortion of the bonded area.

Welding Hytrel to Other Thermoplastics

A limited amount of work has been done on welding Hytrel to other thermoplastics, using the hot plate method.

It should be noted that in some cases it is necessary to use plate temperatures that are higher than those normally recommended for Hytrel-to-Hytrel welding. This may cause stringing of the molten Hytrel. It is sometimes necessary to use different plate contact times and pressures for the two materials.

The following results were obtained when several other thermoplastic materials were hot plate welded to Hytrel. Plate temperatures were normally 300°C (572°F) with melt and weld times of 7–9 sec.

Good Welds	Questionable	No Weld
Polycarbonate	Styrene	ABS
SAN	Polyether sulphone	Polypropylene
Cellulose acetate	EVA	Nylon 6,6
PVC		Polyethylene
		Acrylic

It is emphasized that these are general conclusions, and in any application involving welding of Hytrel to other plastics, trials should be made with the particular grades of material being considered.

Overmolding

Overmolding (or insert molding) is a process in which a thermoplastic material is molded directly onto a second thermoplastic material (the insert). Hytrel generally overmolds best when used with other grades of Hytrel; however, other materials can be used.

The optimum process requires that the insert grade have a relatively low melting point (<190°C [<374°F]), and preferably with a broad melting range for slower crystallization. In order to achieve a good bond, the material used as the overmold should be injected at least 30°C (54°F) higher in melt temperature and be processed at a somewhat higher temperature than is typically used for injection molding. This ensures that the higher melting resin can melt the surface of the insert, thus establishing a good bond.

If these requirements cannot be met, then the design may incorporate a mechanical bond (molded- in mechanical locking devices) or design with some flash or projection that can melt together to form a bond. The insert can also be mechanically abraded or may even require an adhesive to achieve a good bond. In all cases, the insert should be dry and free of grease and oil, which could interfere with a good bond.

Bearings and Seals

Hytrel engineering thermoplastic elastomer has been used in a number of bearing and seal applications where flexibility, chemical resistance, or useful temperature range not found in other elastomers or plastics is required.

A convenient way to assess the suitability of a material for use in unlubricated bearing applications is to determine whether the pressure and velocity (PV) of the proposed bearing is lower than the PV limit for the material under the operating conditions foreseen. The PV limit for a material is the product of limiting bearing pressure MPa (psi) and peripheral velocity m/min (fpm), or bearing pressure and limiting velocity, in a given dynamic system (**Tables 29** and **30**). It describes a critical, easy to recognize change in the bearing performance of the material in the given system. When the PV limit is exceeded, one of the following manifestations may occur:

- melting
- cold flow or creep
- unstable friction
- transition from mild to severe wear

PV limit is generally related to rubbing surface temperature limit. As such, PV limit decreases with increasing ambient temperature. The PV limits determined on any given tester geometry and ambient temperature can rank materials, but translation of test PV limits to other geometries is difficult.

For a given bearing application, the product of PV is independent of the bearing material. Wear is dependent on PV for any material.

The use of experimentally determined PV limits in specific applications should be considered approximate because all pertinent factors are not easily defined. This means that a generous safety factor is an important consideration in bearing design. Some factors known to affect PV limits are:

- absolute pressure
- velocity
- lubrication
- ambient temperature
- clearances
- type of mating materials
- surface roughness

Table 29
PV Limit and Wear Factor
ASTM D 3702, SI Units

Type of Hytrel	PV Limit, $\text{MPa} \times \frac{\text{m}}{\text{min}}$	Wear Factor, *K*, $\frac{\text{mm}^3\cdot\text{min}}{\text{m}\cdot\text{N/hr}} \times 10^{-3}$
G4074	1.1	39
4056	2.1	22
5556	2.1	2.0
6346	6.3	2.1
7246	8.4	0.48

Table 30
PV Limit and Wear Factor
ASTM D 3702, English Units

Type of Hytrel	PV Limit, $\frac{\text{lb}}{\text{in}^2} \times \frac{\text{ft}}{\text{min}}$	Wear Factor, *K*, $\frac{\text{in}^3\cdot\text{min}}{\text{ft}\cdot\text{lb/hr}} \times 10^{-10}$
G4074	500	32,200
4056	1,000	17,900
5556	1,000	1,620
6346	3,000	1,750
7246	4,000	400

As indicated previously, the PV limit decreases with any change that results in increase of the coefficient of friction or reduced heat dissipation from the bearing zone. This observation and industrial experience leads to the following suggestions for bearing design:

- Design bearing sections as thin as is consistent with application requirements. This maximizes heat conduction through the plastic material adjacent to the bearing surface and reduces thermal expansion.
- Metal/plastic bearing interfaces run cooler than plastic/plastic interfaces, because heat is conducted from the interface more rapidly by metal than plastic. Metal/plastic bearings have higher PV limits than plastic/plastic bearings.
- Provision for air circulation about the bearing can bring about cooler operation.
- Lubrication can greatly increase the PV limit, depending on type and quantity of lubrication. Where lubricants are used, these must be stable at the bearing temperature.
- For unlubricated bearings of Hytrel on metal, the metal should be as hard and smooth as is consistent with bearing life requirements and bearing cost.
- Bearing clearance is essential to allow for thermal expansion or contraction and other effects.
- Surface grooves should be provided in the bearing so that wear debris may be cleared from the bearing area. For lubricated bearings, the grooves can increase the supply of lubricant. Bearing pressure will increase with grooving.
- For the bearing applications in dirty environments, use of seals or felt rings can increase bearing life if they are effective in preventing penetration of dirt into the bearing.

Gears

A growing number of applications have shown Hytrel engineering thermoplastic elastomer to be an excellent material for gears. Two factors give Hytrel a decided advantage over some materials in certain applications.

- Greater flexibility compared to plastics and metals used in gears results in quieter operation.
- The ability of Hytrel to be melt cast means that large gears with thick sections can be produced—much larger than is possible by injection molding.

Some other advantages of using Hytrel in gears are as follows:

- Post-machining operations or burr removal are usually not required
- Possible combination of gears with other elements, such as springs, bearings, ratchets, cams, and other gears
- Low weight
- Corrosion resistance
- Electrical insulation
- Shock absorption

Boots and Bellows

Figure 47 shows a blow-molded CVJ boot for automotive axles. Hytrel replaces vulcanized rubber in boots previously used in this application. The higher modulus allows thinner wall thickness at the same strength and lower weight. The production cost of a blow-molded boot is considerably lower than for an injection-molded rubber boot.

An optimized thermoplastic boot differs from the many available rubber boots. The folded edges are flat and have small radii at the tip as depicted in **Figure 48**. It is very important that the boot does not kink when it is being bent as this would lead to a premature failure. Excessive stretching of the boot leads to kinking at the inside. It is vital that the boot be designed in such a way that the original length, as produced, is identical to the maximum extended length in use. This way, the boot is only stressed in compression, and kinking is avoided.

The advantage of a thermoplastic axle boot, as compared with a rubber boot, is that the impact resistance is higher. The Hytrel boot has a longer useful life, and it retains its shape better at high speeds. In addition, the Hytrel boot shows superior low temperature properties.

Figure 47. Automotive CVJ Boot

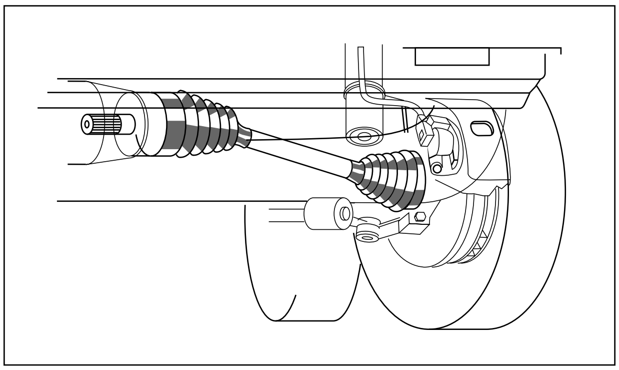
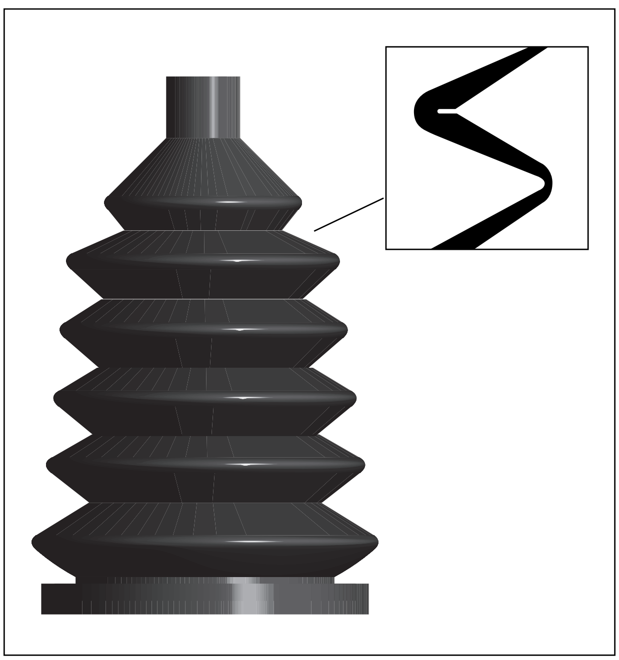


Figure 48. Boot Design



Under dynamic loads, stresses will develop at the tips of the folds. When loaded in flexure up to the maximum deformation, the stress will increase proportionally to the wall thickness in the outer regions of the boot. The flex fatigue resistance, consequently, can be optimized by reducing the wall thickness. However, the tear resistance and the impact resistance are also important considerations. Therefore, the wall thickness can only be reduced to the point that all mechanical requirements are still being met. All these factors combined lead to a lower cost boot.

Rolling Diaphragms

Because of its flexibility and fatigue resistance, Hytrel is suitable for use in many diaphragm applications. Its high modulus, compared to vulcanized rubber, allows a thinner cross section and possible elimination of fabric reinforcement, which combined with thermoplastic processing, often result in a lower cost part.

Pictured in **Figure 49** is a rolling type diaphragm, which provides a longer stroke than a flat diaphragm. A plastic diaphragm of this type must be designed so that there is no circumferential compression of the diaphragm as it rolls from the cylinder wall to the piston, which causes wrinkling or buckling and results in early failure. There are two ways to accomplish this design:

- Use a piston with a tapered skirt to keep the compression to a minimum, as shown in **Figure 50**.
- Design the system so that the piston moves only in the direction that will roll the diaphragm from the piston to the cylinder wall, as related to the molded shape of the diaphragm.

Belts

Hytrel has proven to be an excellent material for power transmission and conveyor belting. It can be made in "V," round, flat, and other configurations. Its high tensile modulus, compared to rubber, eliminates the need for reinforcing cord in many applications, which means that belting can be extruded in long lengths and stocked in rolls. When a belt is needed, a length is cut off and heat spliced to make a finished belt.

Figure 49. Rolling Type Diaphragm

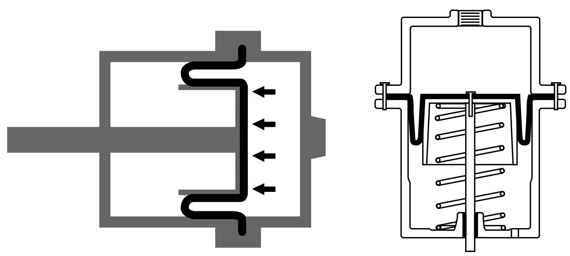


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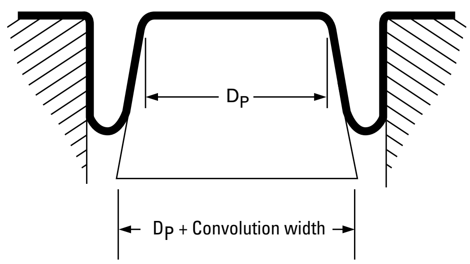
Figure 50. Tapered Piston Skirt



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Belts of Hytrel should be made to the same dimensions as the belts being replaced. In applications involving large diameter pulleys and moderate speeds, belts of Hytrel have outlasted vulcanized rubber belts by a wide margin. Small-diameter pulleys and high speeds should be avoided, as these result in excessive heat buildup and failure of the belt.

Heat splicing of the belt is a simple process, but must be done properly for best results. A 45° bias cut will generally give the best splice. After cutting, the ends to be spliced are heated above the melting point of the material with a heating paddle and then joined together. Two important points are:

- The belt ends must not be pushed so tightly together that the melt is squeezed from between the ends.
- The ends must be held motionless until the melt has solidified. A fixture that will hold the belt ends properly will help ensure a good splice. Flash is trimmed from the splice with a knife or clippers.

Excessive moisture content will cause degradation of the melt in the splice as it does during any other processing operation (see the “Rheology and Handling” bulletin). For best results, the ends of the belt should be dried before splicing or the belting should be stored in a dry atmosphere, such as a heated cabinet.

Coiled Tubing and Cables

Products such as coiled pneumatic tubing and coiled electrical cables are made from Hytrel by winding an extruded profile around a mandrel and then heat setting. The coil will spring back to some extent when released so the mandrel must be smaller than the desired final diameter of the coil. Exact mandrel size must be determined for each application by trial and error.

Recommended temperatures for heat setting are shown in **Table 31**. Parts must be held at the setting temperature only long enough to heat the entire cross section of the part to the setting temperature. Parts may be cooled by air at room temperature and should remain on the mandrel until cooled.

Table 31
Heat Setting Temperature

	Temperature	
Type of Hytrel	**°C**	**°F**
4056	107	225
5556	125	255
6346	125	255
7246	150	300

Reinforced Hose

In the design of reinforced hose, three important factors to consider in the choice of the tube and cover materials are: resistance to the environment in which the hose must operate, strength, and flexibility of the material. Based on these factors and others, Hytrel thermoplastic elastomer has been chosen for several hose applications such as hydraulic and paint spray hose. As a cover, Hytrel offers excellent resistance to abrasion and weathering. UV stabilizer concentrate, Hytrel 20UV, should be added to the cover material if it will be exposed to sunlight. Similarly, thin-walled hose linings of Hytrel must be protected from UV light that passes through the cover. Carbon black is an effective screen (see Effect of Environment on p.

42).

In fire hose and other lay-flat hoses, it is possible to use a tube of Hytrel, which is thinner than a vulcanized rubber tube, making the hoses lighter and easier to handle. Hytrel can be used in SAE100R7 and R8 thermoplastic hydraulic hoses, which offer the advantages of lighter weight and a wider color selection than steel-reinforced rubber hose.

In the design of thin-walled tubing of Hytrel, care must be taken that the expansion of the lining against the cover does not exceed the elastic limit of Hytrel.

If the finished hose is to be coupled, creep, thermal expansion, and cut or notch sensitivity must be considered in the fitting design. Creep data for Hytrel may be calculated from the creep modulus plots (see pages 18 and 19). Sharp edges and burrs should be avoided when designing fittings for hoses based on Hytrel. In all cases, the final fitting design should be tested under actual or closely simulated service conditions to ensure satisfactory performance.

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