DUPONT™ HYTREL® THERMOPLASTIC POLYESTER ELASTOMERS
DESIGN GUIDE

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Section 1 - General Information

Description

Hytrel® is the DuPont registered trademark for its brand of thermoplastic polyester 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 made of Hytrel® thermoplastic polyester elastomers. Many of the same design considerations that apply to metals and other engineering materials of construction apply to 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 that will perform satisfactorily under all these conditions.

The selection of the best material for any application requires the 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.

The information to follow is intended to help designers and engineers become familiar with the unique characteristics of the DuPont family of Hytrel® thermoplastic elastomer resins and how these characteristics are affected by environment and stress. With this knowledge, and the information provided by the Design Guide, it is hoped that proper resin selection coupled with good design practice will result in the development of a successful part in the shortest possible time.

The data contained in this guide falls within the normal range of product properties but should not be used to establish specification limits or used alone as the basis for design. Because DuPont can make no guarantee of results and therefore assumes no liability in connection with the use of this information, confirmation of its validity and suitability should be obtained independently.

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.

Description, typical characteristics and typical application areas of various Hytrel® grades are listed in **Table 1.1**.

Properties and Characteristics

Hytrel® 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.*

Typical properties of various Hytrel® grades are listed in **Table 1.2**, in SI units (pages 4–5), and followed by English units (pages 6–7).

* Property data sheets and other Hytrel® processing guides, as well as this brochure, are available at http://www.plastics.dupont.com.

Processing

Hytrel® can be readily formed into high-performance products by multiple thermoplastic processing techniques, including injection molding, extrusion, blow molding, rotational molding, and melt casting. Hytrel® is processed at temperatures between 180 and 260°C (355 and 500°F), depending on the process and polymer type. All standard grades have a specific melting point and very good melt stability.

Additional information on processing Hytrel® can be found in the *Hytrel® Molding Guide*, *Hytrel® Extrusion Guide*, *Blow Molding Processing Manuel* and *DuPont™ Hytrel® Handling and Processing Precautions*.

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 multi-piece 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 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.

Table 1.1

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® 3078	Very low modulus molding and extrusion grade. Contains color-stable antioxidants.	Most flexible grade of Hytrel® with excellent strength and toughness over a wide temperature range.	Applications requiring flex life coupled with good flexibility at very low temperatures. Thin, flexible membranes.
Hytrel® 4056	Low modulus extrusion grade. Contains color-stable antioxidants.	Excellent low-temperature properties, flex-fatigue resistance and creep resistance.	Hose jackets, Wire and cable jackets, Film and sheeting, Belting, Seals
Hytrel® 4056P	Similar to Hytrel® 4056 in powder form.	Similar to Hytrel® 4056.	Applications requiring specific processes such as roto-molding.
Hytrel® 4068 Hytrel® 4069	Low modulus molding and extrusion grades. Contains color-stable antioxidants (in particular Hytrel® 4068).	Low modulus grades similar to Hytrel® 4056 with a higher melting point.	Hose jackets, Wire and cable jackets, Film and sheeting, Belting, Seals, Molded products
Hytrel® 4556	Medium-low modulus molding and extrusion grade. Contains color-stable antioxidants.	Same as Hytrel® 4069.	Hose jackets, Wire and cable jackets, Film and sheeting, Belting, Seals, Molded products
Hytrel® 5526	Medium modulus molding grade. Contains color-stable antioxidants.	Good balance of properties.	Seals, packing, and gaskets Gears and bearings
Hytrel® 5556	Medium modulus extrusion grade. Contains color-stable antioxidants.	Good balance of properties.	Tubing and hose, Wire and cable jackets, Film and sheeting, Belting
Hytrel® 5555HS	Heat-stabilized grade of Hytrel® 5556. Contains a discoloring antioxidant. Not suited for light-colored products.	Good balance of properties. Used where increased heat-aging stability is required.	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 balance of flexibility, toughness, strength and thermal and creep resistance.	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 grade (can be extruded in certain cases). Contains color-stable antioxidants.	Highest service temperature. Excellent resistance to oils, fuels, and solvents. Lowest fuel permeability.	Tubing, Wire and cable jackets, Gears and sprockets, Oil field parts, Electrical connectors

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

Table 1.1, continued

General Purpose Hytrel® Resins These grades offer the best balance of properties and cost.			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® G3548 NC010	Low modulus molding and extrusion grade. Contains color-stable antioxidants.	Very flexible grade with excellent flex resistance, especially at low temperatures. Moldable in thin & thick 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. Not suited for light-colored products.	Excellent heat-aging resistance and resistance to oils at high temperatures. Best low modulus molding and extrusion grade.	Tubing, Hose jackets, Wire & cable jackets, Film and sheeting, Molded products
Hytrel® G4078 NC010	Low modulus molding and extrusion grade.	Like Hytrel® G4074, except that heat-aging resistance is reduced.	Molded and extruded products for consumer use.
Hytrel® G4078LS NC010	Low modulus molding and extrusion grade. Contains 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	Low to medium modulus molding and extrusion grade. Contains a discoloring antioxidant. Not suited for light-colored products.	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® G5544	Medium modulus molding and extrusion grade. Contains a discoloring antioxidant. Not suited for light-colored products.	Excellent heat-aging resistance and resistance to oils at high temperatures.	Tubing, Hose jackets, Wire and cable jackets, Profiles, Molded products

Blow Moldable Hytrel® Resins These grades show excellent melt strength for processes requiring specific melt elongation resistance such as blow molding.			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® BM6574 BK316	A 65 nom. Shore D, heat stable, plasticizer-free high performance resin for blow molding.	High viscosity; ageing resistance up to 150°C, excellent mechanical properties at elevated temperatures.	Air ducts Hollow thin-walled parts Large diameter tubing Profiles
Hytrel® HTR4275 BK316	A 56 nom. Shore D, heat stable, plasticizer-free high performance resin for blow molding and extrusion; excellent mechanical properties at elevated temperatures.	Excellent overall properties combined with high viscosity for extrusion and blow molding applications.	Air ducts Hollow thin-walled parts Blow film and sheeting Large diameter tubing Hose mandrels Profiles Automotive boots and covers
Hytrel® HTR8441 BK316	A 55 nom. Shore D, for blow molding. It provides good mechanical properties at high temperature.	Good balance of properties combined with high viscosity for extrusion and blow molding applications.	Air ducts Hollow thin-walled parts Blow film and sheeting Large diameter tubing Hose mandrels Profiles Automotive boots and covers

Blow Moldable Hytrel® Resins for automotive boots These grades show excellent melt strength combined with excellent flex fatigue at different temperatures.			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® HTR237BG BK320	A 45 nominal Shore D, plasticizer-free high performance resin for blow molding or processing techniques requiring high viscosity	Improved wet-squeak resistance	Automotive boots and covers
Hytrel® HTR8139BK	A 44 nom. Shore D, heat stable, plasticizer-free high performance resin for blow molding and extrusion.	Excellent flex fatigue resistance and excellent performance at low temperature. Formulated for improved surface lubricity.	Automotive boots and covers Hollow thin-walled parts Blow film and sheeting Large diameter tubing Profiles
Hytrel® HTR8223 BK320	A 49 nom. Shore D, heat stable, plasticizer-free high performance resin for blow molding and extrusion.	High viscosity/melt strength; excellent mechanical properties at elevated temperatures and fatigue resistance.	Hollow thin-walled parts Large diameter tubing Profiles Automotive boots and covers
Hytrel® HTR8341C BK320	A 40 nom. Shore D, heat stable, plasticizer-free resin for blow molding and extrusion.	High viscosity/melt strength; excellent mechanical properties at elevated temps; superior fatigue, abrasion, and grease resistance.	Automotive boots and covers Hollow thin-walled parts Blow film and sheeting Large diameter tubing Profiles
Hytrel® HTR8685 BK022A	46D, "wet squeak" lubricated		

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

Table 1.1, continued

Specialty Hytrel® Resins			
Many general purpose and high-performance Hytrel® resins can be processed by extrusion.			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® 5586	A 55 nom. Shore D medium modulus grade with higher viscosity for extrusion applications	Outstanding balance of properties. Higher viscosity than 5556.	Large diameter tubing, profiles
Hytrel® HTR6108	Medium-low modulus grade. Contains color-stable antioxidants. Translucent in thin applications.	Low permeability to oils, fuels, and plasticizers. 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.
Hytrel® HTR8163HVBK	A 65 nom. Shore D, heat stabilized, plasticizer free high performance resin for extrusion.	Low temperature impact, excellent heat ageing, fatigue and crack propagation resistance.	Air brake tubes Profiles Large diameter tubing
Hytrel® HTR8206	High performance polyester elastomer with high moisture vapor transmission rate developed for extrusion and injection molding	Breathability	Film applications
Hytrel® HTR8303	A 65 nom. Shore D, viscosity modified extrusion/blow molding resin.	Excellent high temperature properties and hydrolytic stability.	Wire and cable jackets

Flame Retardant Hytrel® Resins			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® HTR8068	A 44 nom. Shore D resin for molding and extrusion. Flame retarded antidrip compound, halogenated.	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

Hytrel® DYM Resins			
These grades provide service over a broad temperature range maintaining flexibility and impact strength. They can be painted without the use of adhesion promoters or primers.			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® DYM250S BK472	A medium modulus resin suited for injection molding.	Excellent impact strength at low and high temperatures with a flexural modulus at 23°C of 250MPa	Airbag Deployment Doors
Hytrel® DYM350BK	A medium/high modulus polyester alloy suited for injection molding.	Excellent impact strength at low and high temperatures with a flexural modulus at 23°C of 400MPa	Airbag Deployment Doors

Food Contact Approved Hytrel® Grades			
Please refer to "Agency Approvals" chapter. For more information, contact your DuPont representative.			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® 3078FG	Very low modulus molding and extrusion grade. Contains color-stable antioxidants.	Most flexible grade of Hytrel® with excellent strength and toughness over a wide temperature range.	Applications requiring flex life coupled with good flexibility at very low temperatures. Thin, flexible membranes.
Hytrel® 4053FG NC010	Low modulus extrusion grade. Contains color-stable antioxidants.	Excellent low-temperature properties, flex-fatigue resistance and creep resistance.	Film and sheeting, Belting, Seals
Hytrel® 4068FG	Low modulus molding and extrusion grade. Contains color-stable antioxidants.	Low modulus grade similar to Hytrel® 4053FG with a higher melting point.	Same as Hytrel® 4056 and molded products.
Hytrel® 5553FG NC010	Medium modulus molding and extrusion grade. Contains color-stable antioxidants.	Outstanding balance of properties.	Film, Profiles, Seals, Gears and sprockets
Hytrel® 6359FG NC010	Medium-high modulus molding and extrusion grade. Contains color-stable antioxidants.	Very good balance of flexibility, toughness, strength and thermal and creep resistance.	Film, Profiles, Seals, Gears and sprockets

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

Table 1.1, continued

Hytrel® RS grades ***Hytrel® RS thermoplastic elastomers are made using renewably-sourced polyol derived from plant feedstocks.***			
Grade	**Description**	**Characteristics**	**Typical Uses**
Hytrel® RS 40F2 NC010	A low modulus grade with a low melting point, containing at least 38% renewably sourced ingredients by weight. For injection molding and extrusion.	Excellent low-temperature properties. Excellent flex-fatigue resistance. Excellent creep resistance. Equivalent to HYT4056.	Hose jackets Wire and cable jackets Film and sheeting Belting Seals Compounding formulation
Hytrel® RS 40F3 NC010	A high flow, low modulus grade containing at least 50% renewably sourced ingredients by weight. For injection molding.	Excellent low-temperature properties. Excellent flex-fatigue resistance. Excellent creep resistance.	Seals Filaments
Hytrel® RS 40F5 NC010	A low modulus grade containing at least 50% renewably sourced ingredients by weight. For many conventional thermoplastic processing techniques such as injection molding and extrusion.	Excellent low-temperature properties. Excellent flex-fatigue resistance. Excellent creep resistance. Equivalent to HYT4069.	Hose jackets Wire and cable jackets Film and sheeting Belting Seals
Hytrel® RS 55F5 NC010	A medium modulus grade containing at least 30% renewably sourced ingredients by weight. For many thermoplastic processing techniques like injection molding and extrusion.	Combine the best balance of properties of the product line (equivalent to HYT5556).	Tubing and hose Wire and cable jackets Film and sheeting Belting
Hytrel® RS 63F5 NC010	A medium modulus grade containing at least 22% renewably sourced ingredients by weight. For many thermoplastic processing techniques like injection molding and extrusion.	Very good balance of flexibility, toughness, strength and thermal and creep resistance.	Tubing and hose Film Profiles Seals Gears and sprockets Fuel tanks

Hytrel® SC and PC for healthcare components ***For more information, contact your DuPont representative.***
Depending on the specific application, DuPont can provide options from its broad range of "Special Control" (SC) and "Premium Control" (PC) grades, which are differentiated by a greater degree of testing, manufacturing control and regulatory support.

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

Table 1.2 - Typical Properties of Hytrel®

					High Performance Grades				
					Hytrel® 3078	Hytrel® 4056	Hytrel® 4068	Hytrel® 4069	Hytrel® 4556
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	5	5	8.8	8.8	7.5
		Temperature		°C	190	190	220	220	220
		Load		kg	2.16	2.16	2.16	2.16	2.16
	Melt Mass-Flow Rate		ISO 1133	g/10 min	5	5.6	8.5	8.5	8.5
		Temperature		°C	190	190	220	220	220
		Load		kg	2.16	2.16	2.16	2.16	2.16
	Molding Shrinkage	Parallel	ISO 294-4	%	0.6	0.2	0.8	0.8	1.1
		Normal			0.6	0.4	0.8	0.8	1.1
Mechanical	Stress at Break		ISO 527-1/-2	MPa	24	26	29	29	34
				kpsi	3.5	3.8	4.2	4.2	4.9
	Stress at	5% Strain	ISO 527-1/-2	MPa	-	2.4	2.4	-	-
				kpsi	-	0.3	0.3	-	-
		10% Strain		MPa	1.8	4.6	3.2	3.2	5.7
				kpsi	0.3	0.7	0.5	0.5	0.8
		50% Strain		MPa	5	8.4	6.7	6.7	9.8
				kpsi	0.7	1.2	1	1	1.4
	Strain at Break		ISO 527-1/-2	%	>300	>300	>300	>300	>300
	Nominal Strain at Break		ISO 527-1/-2	%	900	500	800	800	740
	Tensile Modulus		ISO 527-1/-2	MPa	24	60	45	45	85
				kpsi	3.5	8.7	6.5	6.5	12.3
	Flexural Modulus		ISO 178	MPa	21	64	45	45	87
				kpsi	3	9.3	6.5	6.5	12.6
	Tensile Creep Modulus	1h	ISO 899-1	MPa	22	54	28	-	-
				kpsi	3.2	7.8	4.1	-	-
		1000h		MPa	18	40	21	-	-
				kpsi	2.6	5.8	3	-	-
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	N	N	N	N	N
		23°C			N	N	N	N	N
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	N	N	N	N	N
		-30°C			N	N	N	N	N
		23°C			N	N	N	N	N
	Tear Strength	Parallel	ISO 34-1	kN/m	80	102	100	100	122
		Normal			77	96	103	100	123
	Abrasion Resistance		ISO 4649	mm^3	-	200	180	-	130
	Shore D Hardness	15 s	ISO 868		26	37	33	33	42
		max			30	43	37	37	45
Thermal	Melting Temperature		ISO 11357-1/-3	°C	177	152	193	193	193
				°F	351	306	379	379	379
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-60	-50	-55	-50	-45
				°F	-76	-58	-67	-58	-49
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	-	-	-	-	35
				°F	-	-	-	-	95
		0.45 MPa		°C	-	48	-	49	50
				°F	-	118	-	120	122
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	-	-	-	-	60
				°F	-	-	-	-	140
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	177	130	230	220	171
				E-6/°F	98	72	128	122	95
		Normal		E-6/°K	206	160	230	190	187
				E-6/°F	114	89	128	106	104
Other	Water Absorption, 2mm		ISO 62	%	0.8	0.7	0.7	0.7	0.6
	Humidity Absorption, 2mm				0.2	0.2	0.3	0.3	0.2
	Water Absorption, Immersion 24h		ASTM D 570	%	0.5	0.6	0.7	0.7	0.6
	Density		ISO 1183	g/cm^3	1.07	1.16	1.11	1.11	1.14

Note: 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 for design.
[P] = Partial Break

Table 1.2, continued - Typical Properties of Hytrel®

					High Performance Grades, continued					
					Hytrel® 5526	Hytrel® 5555HS	Hytrel® 5556	Hytrel® 6356	Hytrel® 7246	Hytrel® 8238
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	17.5	8.5	7	8.5	12	11.5
		Temperature		°C	220	220	220	230	240	240
		Load		kg	2.16	2.16	2.16	2.16	2.16	2.16
	Melt Mass-Flow Rate		ISO 1133	g/10 min	18	8.5	7.8	9	12.5	12.5
		Temperature		°C	220	220	220	230	240	240
		Load		kg	2.16	2.16	2.16	2.16	2.16	2.16
	Molding Shrinkage	Parallel	ISO 294-4	%	1.4	1.5	1.4	1.5	1.6	1.6
		Normal			1.4	1.5	1.4	1.5	1.6	1.6
Mechanical	Stress at Break		ISO 527-1/-2	MPa	43	35	40	43	50	46
				kpsi	6.2	5.1	5.8	6.2	7.3	6.7
	Stress at	5% Strain	ISO 527-1/-2	MPa	6.9	6.9	6.9	12	14	-
				kpsi	1	1	1	1.7	2	-
		10% Strain		MPa	11	11.1	11	15	23	34
				kpsi	1.6	1.6	1.6	2.2	3.3	4.9
		50% Strain		MPa	14	14.7	14.5	18.8	24	28
				kpsi	2	2.1	2.1	2.7	3.5	4.1
	Strain at Break		ISO 527-1/-2	%	>300	>300	>300	>300	>300	>300
	Nominal Strain at Break		ISO 527-1/-2	%	780	640	600	500	530	340
	Tensile Modulus		ISO 527-1/-2	MPa	190	190	180	280	525	1180
				kpsi	27.6	27.6	26.1	40.6	76.1	171
	Flexural Modulus		ISO 178	MPa	200	195	190	290	550	1150
				kpsi	29	28.3	27.6	42.1	79.8	167
	Tensile Creep Modulus	1h	ISO 899-1	MPa	170	140	170	248	360	-
				kpsi	24.7	20.3	24.7	36	52.2	-
		1000h		MPa	130	100	133	182	310	-
				kpsi	18.9	14.5	19.3	26.4	45	-
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	N	-	N	-	-	-
		23°C			N	N	N	-	-	-
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	30	25	145[P]	15	7	5
		-30°C			150[P]	43	145[P]	25	8	5
		23°C			N	-	N	120[P]	36	15
	Tear Strength	Parallel	ISO 34-1	kN/m	133	134	137	158	182	228
		Normal			133	124	134	145	172	212
	Abrasion Resistance		ISO 4649	mm^3	120	120	120	110	100	-
	Shore D Hardness	15 s	ISO 868		51	52	51	57	64	70
		max			55	55	55	63	68	76
Thermal	Melting Temperature		ISO 11357-1/-3	°C	203	201	201	210	218	221
				°F	397	394	394	410	424	430
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-20	-	-20	0	25	50
				°F	-4	-	-4	32	77	122
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	45	51	45	45	50	45
				°F	113	124	113	113	122	113
		0.45 MPa		°C	65	78	70	80	100	105
				°F	149	172	158	176	212	221
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	75	75	75	100	140	150
				°F	167	167	167	212	284	302
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	197	180	180	178	177	147
				E-6/°F	109	100	100	99	98	82
		Normal		E-6/°K	186	177	177	176	173	149
				E-6/°F	103	98	98	98	96	83
Other	Water Absorption, 2mm		ISO 62	%	0.6	0.6	0.6	0.6	0.6	0.6
	Humidity Absorption, 2mm				0.2	0.2	0.2	0.2	0.2	0.2
	Water Absorption, Immersion 24h		ASTM D 570	%	0.6	0.7	0.6	0.5	0.3	0.3
	Density		ISO 1183	g/cm^3	1.19	1.19	1.19	1.22	1.26	1.28

Note: 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 for design.
[P] = Partial Break

Table 1.2, continued - Typical Properties of Hytrel®

	Property	Condition	Standard	Unit	Hytrel® G3548 NC010	Hytrel® G4074	Hytrel® G4078 NC010	Hytrel® G4078LS NC010	Hytrel® G4774	Hytrel® G5544
					General Purpose Grades					
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	-	5	-	-	11	10
		Temperature		°C	-	190	-	-	230	230
		Load		kg	-	2.16	-	-	2.16	2.16
	Melt Mass-Flow Rate		ISO 1133	g/10 min	-	5.3	-	6.5	11	10
		Temperature		°C	-	190	-	190	230	230
		Load		kg	-	2.16	-	2.16	2.16	2.16
	Molding Shrinkage	Parallel	ISO 294-4	%	0.8	0.8	0.5	0.5	1.5	1.6
		Normal			0.8	0.8	1.1	1.1	1.2	1.6
Mechanical	Stress at Break		ISO 527-1/-2	MPa	10	20	16	21	17	33
				kpsi	1.5	2.9	2.3	3	2.5	4.8
	Stress at	5% Strain	ISO 527-1/-2	MPa	1.5	2.5	2.5	-	-	8.1
				kpsi	0.2	0.4	0.4	-	-	1.2
		10% Strain		MPa	2.5	4.4	4.2	4.2	7	11.7
				kpsi	0.4	0.6	0.6	0.6	1	1.7
		50% Strain		MPa	6	8	8.5	-	12	9
				kpsi	0.9	1.2	1.2	-	1.7	1.3
	Strain at Break		ISO 527-1/-2	%	190	250	220	>300	200	>300
	Nominal Strain at Break		ISO 527-1/-2	%	200	360	250	-	400	290
	Tensile Modulus		ISO 527-1/-2	MPa	25	55	55	54	110	200
				kpsi	3.6	8.0	8.0	7.8	16.0	29.0
	Flexural Modulus		ISO 178	MPa	25	65	-	58	111	190
				kpsi	3.6	9.4	-	8.4	16.1	27.6
	Tensile Creep Modulus	1h	ISO 899-1	MPa	-	45	-	-	-	110
				kpsi	-	6.5	-	-	-	16
		1000h		MPa	-	35	-	-	-	85
				kpsi	-	5.1	-	-	-	12.3
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	-	N	-	-	N	-
		23°C			-	N	-	-	N	N
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	N	-	-	N	120[P]	14
		-30°C			N	N	-	-	N	45
		23°C			N	N	N	N	N	90[P]
	Tear Strength	Parallel	ISO 34-1	kN/m	60	86	-	70	100	123
		Normal			80	96	120	-	90	112
	Abrasion Resistance		ISO 4649	mm^3	-	50	-	-	33	-
	Shore D Hardness	15 s	ISO 868		24	35	33	-	43	51
		max			-	40	-	-	48	56
Thermal	Melting Temperature		ISO 11357-1/-3	°C	157	170	170	175	208	214
				°F	315	338	338	347	406	417
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-	-35	-	-	-45	-35
				°F	-	-31	-	-	-49	-31
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	-	-	-	-	-	-
				°F	-	-	-	-	-	-
		0.45 MPa		°C	-	-	-	-	60	77
				°F	-	-	-	-	140	171
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	-	-	-	-	-	-
				°F	-	-	-	-	-	-
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	-	217	-	-	220	211
				E-6/°F	-	121	-	-	122	117
		Normal		E-6/°K	-	205	-	-	190	186
				E-6/°F	-	114	-	-	106	103
Other	Water Absorption, 2mm		ISO 62	%	12	3.7	6.5	6.8	-	2.2
	Humidity Absorption, 2mm				0.8	0.4	0.7	0.7	-	0.4
	Water Absorption, Immersion 24h		ASTM D 570	%	6.9	2.1	3.4	3.5	2.5	1.6
	Density		ISO 1183	g/cm^3	1.15	1.18	1.18	1.18	1.19	1.22

Note: 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 for design.
[P] = Partial Break

Table 1.2, continued - Typical Properties of Hytrel®

	Property	Condition	Test Method	Units	Specialty Grades: Hytrel® 5586	Hytrel® HTR6108	Hytrel® HTR8163HVBK	Hytrel® HTR8206	Hytrel® HTR8303
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	5	5.2	5	14	3
		Temperature		°C	220	190	230	220	250
		Load		kg	2.16	2.16	2.16	2.16	10
	Melt Mass-Flow Rate		ISO 1133	g/10 min	4.5	-	5	-	4.5
		Temperature		°C	220	-	230	-	250
		Load		kg	2.16	-	2.16	-	10
	Molding Shrinkage	Parallel	ISO 294-4	%	1.4	0.3	-	1.4	2.6
		Normal			1.4	0.7	-	1.5	2.5
Mechanical	Stress at Break		ISO 527-1/-2	MPa	30	17	44	20	26
				kpsi	4.4	2.5	6.4	2.9	3.8
	Stress at	5% Strain	ISO 527-1/-2	MPa	-	5.5	12	3.4	16
				kpsi	-	0.8	1.7	0.5	2.3
		10% Strain		MPa	10	7.5	17.8	5.4	18
				kpsi	1.5	1.1	2.6	0.8	2.6
		50% Strain		MPa	-	9.5	20	9.5	22
				kpsi	-	1.4	2.9	1.4	3.2
	Strain at Break		ISO 527-1/-2	%	>300	160	>300	>300	190
	Nominal Strain at Break		ISO 527-1/-2	%	-	270	-	420	180
	Tensile Modulus		ISO 527-1/-2	MPa	180	110	350	80	680
				kpsi	26.1	16.0	50.8	11.6	98.6
	Flexural Modulus		ISO 178	MPa	-	120	374	80	750
				kpsi	-	17.4	54.2	11.6	109
	Tensile Creep Modulus	1h	ISO 899-1	MPa	-	-	310	-	-
				kpsi	-	-	45	-	-
		1000h		MPa	-	-	260	-	-
				kpsi	-	-	37.7	-	-
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	N	-	-	N	-
		23°C			N	-	-	N	-
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	-	3.5	8.5	-	10
		-30°C			N	4.5	12	N	15
		23°C			N	-	130[P]	N	100
	Tear Strength	Parallel	ISO 34-1	kN/m	158	110	176	-	140
		Normal			-	120	-	-	145
	Abrasion Resistance		ISO 4649	mm^3	-	-	110	-	-
	Shore D Hardness	15 s	ISO 868		-	55	60	38	62
		max			55	61	65	40	65
Thermal	Melting Temperature		ISO 11357-1/-3	°C	203	165	211	200	221
				°F	397	329	412	392	430
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-25	-	-	-	-
				°F	-13	-	-	-	-
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	40	-	-	-	-
				°F	104	-	-	-	-
		0.45 MPa		°C	70	47	85	-	89
				°F	158	117	185	-	192
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	75	-	-	-	-
				°F	167	-	-	-	-
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	-	-	-	-	-
				E-6/°F	-	-	-	-	-
		Normal		E-6/°K	-	-	-	-	-
				E-6/°F	-	-	-	-	-
Other	Water Absorption, 2mm		ISO 62	%	0.5	-	-	35	-
	Humidity Absorption, 2mm				0.2	-	-	1.3	-
	Water Absorption, Immersion 24h		ASTM D 570	%	-	-	-	30	0.4
	Density		ISO 1183	g/cm^3	1.20	1.25	1.23	1.19	1.15

Note: 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 for design.
[P] = Partial Break

Table 1.2, continued - Typical Properties of Hytrel®

					Flame Retardant	Hytrel® DYM Grades		Blow Molding Grades		
					Hytrel® HTR8068	Hytrel® DYM250S BK472	Hytrel® DYM350BK	Hytrel® BM6574 BK316	Hytrel® HTR4275 BK316	Hytrel® HTR8441 BK316
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	3.6	13	14	-	6	10
		Temperature		°C	190	240	240	-	230	240
		Load		kg	2.16	2.16	2.16	-	10	10
	Melt Mass-Flow Rate		ISO 1133	g/10 min	4	13	15	-	6	10
		Temperature		°C	190	240	240	-	230	240
		Load		kg	2.16	2.16	2.16	-	10	10
	Molding Shrinkage	Parallel	ISO 294-4	%	1.1	1.2	1.3	-	1.7	2.2
		Normal			1.1	1.2	1.4	-	1.9	2.1
Mechanical	Stress at Break		ISO 527-1/-2	MPa	13	30	35	30	37	35
				kpsi	1.9	4.4	5.1	4.4	5.4	5.1
	Stress at	5% Strain	ISO 527-1/-2	MPa	-	7.8	10.5	-	6.7	7.8
				kpsi	-	1.1	1.5	-	1	1.1
		10% Strain		MPa	5.9	9.7	13	21	10.4	11.9
				kpsi	0.9	1.4	1.9	3	1.5	1.7
		50% Strain		MPa	7.3	12.5	16	-	17	19
				kpsi	1.1	1.8	2.3	-	2.5	2.8
	Strain at Break		ISO 527-1/-2	%	>300	>300	>300	200	>300	>300
	Nominal Strain at Break		ISO 527-1/-2	%	340	600	600	-	450	380
	Tensile Modulus		ISO 527-1/-2	MPa	140	295	370	690	160	190
				kpsi	20.3	42.8	53.7	100	23.2	27.6
	Flexural Modulus		ISO 178	MPa	155	350	430	-	170	-
				kpsi	22.5	50.8	62.4	-	24.7	-
	Tensile Creep Modulus	1h	ISO 899-1	MPa	-	-	-	-	137	-
				kpsi	-	-	-	-	19.9	-
		1000h		MPa	-	-	-	-	91	-
				kpsi	-	-	-	-	13.2	-
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	-	-	N	-	-	-
		23°C			-	-	N	-	N	N
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	5	120[P]	130[P]	-	30	20
		-30°C			7	110[P]	120[P]	13	160[P]	39
		23°C			40	-	-	100	N	N
	Tear Strength	Parallel	ISO 34-1	kN/m	70	110	130	-	140	140
		Normal			70	90	105	-	100	-
	Abrasion Resistance		ISO 4649	mm^3	-	-	-	-	-	-
	Shore D Hardness	15 s	ISO 868		38	44	50	62	52	52
		max			44	49	55	-	55	58
Thermal	Melting Temperature		ISO 11357-1/-3	°C	170	222	222	220	192	211
				°F	338	432	432	428	378	412
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-	-	-55	-	-30	-
				°F	-	-	-67	-	-22	-
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	41	41	40	-	41	-
				°F	106	106	104	-	106	-
		0.45 MPa		°C	46	48	50	-	57	-
				°F	115	118	122	-	135	-
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	-	-	-	-	-	-
				°F	-	-	-	-	-	-
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	150	-	180	-	181	-
				E-6/°F	83	-	100	-	101	-
		Normal		E-6/°K	170	-	180	-	185	-
				E-6/°F	94	-	100	-	103	-
Other	Water Absorption, 2mm		ISO 62	%	-	-	0.6	-	0.5	-
	Humidity Absorption, 2mm				-	-	0.2	-	0.2	-
	Water Absorption, Immersion 24h		ASTM D 570	%	1.9	-	0.6	-	0.5	-
	Density		ISO 1183	g/cm^3	1.43	1.16	1.18	1.15	1.17	1.19

Note: 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 for design.
[P] = Partial Break

Table 1-2, continued - Typical Properties of Hytrel®

					Blow Modabale CVJ Boot Grades				
					Hytrel® HTR237BG BK320	Hytrel® HTR8139BK	Hytrel® HTR8223 BK320	Hytrel® HTR8341C BK320	Hytrel® HTR8685 BK022A
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	4	1.9	10	-	-
		Temperature		°C	220	230	230	-	-
		Load		kg	10	2.16	10	-	-
	Melt Mass-Flow Rate		ISO 1133	g/10 min	0.4	2.1	9.5	0.9	-
		Temperature		°C	220	230	230	230	-
		Load		kg	2.16	2.16	10	2.16	-
	Molding Shrinkage	Parallel	ISO 294-4	%	-	1.6	1.6	-	1.7
		Normal			-	1.4	1.6	-	1.6
Mechanical	Stress at Break		ISO 527-1/-2	MPa	30	32	26	28	30
				kpsi	4.4	4.6	3.8	4.1	4.4
	Stress at	5% Strain	ISO 527-1/-2	MPa	-	4.5	3.5	-	-
				kpsi	-	0.7	0.5	-	-
		10% Strain		MPa	7.6	6.7	5.5	7	8.4
				kpsi	1.1	1	0.8	1	1.2
		50% Strain		MPa	12.1	11.8	10	12	14
				kpsi	1.8	1.7	1.5	1.7	2
	Strain at Break		ISO 527-1/-2	%	>300	>300	>300	>300	>300
	Nominal Strain at Break		ISO 527-1/-2	%	-	510	680	350	350
	Tensile Modulus		ISO 527-1/-2	MPa	90	55	75	80	100
				kpsi	13.1	8.0	10.9	11.6	14.5
	Flexural Modulus		ISO 178	MPa	90	87	79	80	100
				kpsi	13.1	12.6	11.5	11.6	14.5
	Tensile Creep Modulus	1h	ISO 899-1	MPa	-	-	-	-	-
				kpsi	-	-	-	-	-
		1000h		MPa	-	-	-	-	-
				kpsi	-	-	-	-	-
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	-	N	-	N	-
		23°C			-	N	-	N	-
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	119[P]	N	109[P]	N[3]	-
		-30°C			-	N	-	-	-
		23°C			N	N	N	N	N
	Tear Strength	Parallel	ISO 34-1	kN/m	117	-	124	110	112
		Normal			119	-	130	115	109
	Abrasion Resistance		ISO 4649	mm^3	-	-	22	-	-
	Shore D Hardness	15 s	ISO 868		41	40	38	37	41
		max			45	44	42	40	44
Thermal	Melting Temperature		ISO 11357-1/-3	°C	204	194	195	207	206
				°F	399	381	383	405	403
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-45	-45	-50	-40	-
				°F	-49	-49	-58	-40	-
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	41	44	-	42	-
				°F	106	111	-	108	-
		0.45 MPa		°C	57	58	-	56	62
				°F	135	136	-	133	144
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	-	-	-	-	-
				°F	-	-	-	-	-
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	-	176	170	177	210
				E-6/°F	-	98	94	98	117
		Normal		E-6/°K	-	187	170	202	200
				E-6/°F	-	104	94	112	111
Other	Water Absorption, 2mm		ISO 62	%	-	0.7	0.8	0.5	-
	Humidity Absorption, 2mm				-	0.2	0.2	0.2	-
	Water Absorption, Immersion 24h		ASTM D 570	%	-	0.7	0.6	-	-
	Density		ISO 1183	g/cm^3	1.15	1.15	1.13	1.14	1.15

Note: 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 for design.
[P] = Partial Break

Table 1.2, continued - Typical Properties of Hytrel®

	Property	Condition	Test Method	Unit	Food Contact Approved Grades				
					Hytrel® 3078FG	Hytrel® 4053FG NC010	Hytrel® 4068FG	Hytrel® 5553FG NC010	Hytrel® 6359FG NC010
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	5.3	5	8.8	7	8.5
		Temperature		°C	190	190	220	220	230
		Load		kg	2.16	2.16	2.16	2.16	2.16
	Melt Mass-Flow Rate		ISO 1133	g/10 min	5	5.3	8.5	8	9
		Temperature		°C	190	190	220	220	230
		Load		kg	2.16	2.16	2.16	2.16	2.16
	Molding Shrinkage	Parallel	ISO 294-4	%	0.6	0.2	0.8	1.4	1.5
		Normal			0.6	0.4	0.8	1.4	1.5
Mechanical	Stress at Break		ISO 527-1/-2	MPa	23	26	29	40	41
				kpsi	3.3	3.8	4.2	5.8	5.9
	Stress at	5% Strain	ISO 527-1/-2	MPa	-	2.4	2.4	6.6	12
				kpsi	-	0.3	0.3	1	1.7
		10% Strain		MPa	1.1	4.1	3.5	10.2	15
				kpsi	0.2	0.6	0.5	1.5	2.2
		50% Strain		MPa	4.1	7.3	6.7	-	-
				kpsi	0.6	1.1	1	-	-
	Strain at Break		ISO 527-1/-2	%	>300	>300	>300	>300	>300
	Nominal Strain at Break		ISO 527-1/-2	%	860	-	800	600	-
	Tensile Modulus		ISO 527-1/-2	MPa	24	56	45	170	260
				kpsi	3.5	8.1	6.5	24.7	37.7
	Flexural Modulus		ISO 178	MPa	21	-	47	-	-
				kpsi	3	-	6.8	-	-
	Tensile Creep Modulus	1h	ISO 899-1	MPa	-	50	28	-	-
				kpsi	-	7.3	4.1	-	-
		1000h		MPa	-	40	21	-	-
				kpsi	-	5.8	3	-	-
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	-	N	N	N	-
		23°C			-	N	N	N	-
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	N	N	-	145[P]	15
		-30°C			-	N	N	-	25
		23°C			-	N	N	N	120[P]
	Tear Strength	Parallel	ISO 34-1	kN/m	76	110	100	-	158
		Normal			77	-	103	-	145
	Abrasion Resistance		ISO 4649	mm^3	-	-	180	-	-
	Shore D Hardness	15 s	ISO 868		26	38	33	51	58
		max			30	-	37	56	63
Thermal	Melting Temperature		ISO 11357-1/-3	°C	167	150	193	201	211
				°F	333	302	379	394	412
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-60	-50	-55	-20	-
				°F	-76	-58	-67	-4	-
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	-	-	-	45	45
				°F	-	-	-	113	113
		0.45 MPa		°C	-	50	-	70	85
				°F	-	122	-	158	185
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	-	-	-	75	100
				°F	-	-	-	167	212
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	-	220	230	-	-
				E-6/°F	-	122	128	-	-
		Normal		E-6/°K	-	220	230	-	-
				E-6/°F	-	122	128	-	-
Other	Water Absorption, 2mm		ISO 62	%	0.8	0.7	0.7	0.6	0.6
	Humidity Absorption, 2mm				0.2	0.2	0.3	0.2	0.2
	Water Absorption, Immersion 24h		ASTM D 570	%	-	-	-	0.6	-
	Density		ISO 1183	g/cm^3	1.07	1.16	1.11	1.2	1.22

Note: 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 for design.
[P] = Partial Break

Table 1.2, continued - Typical Properties of Hytrel®

					Renewable Sourced Grades				
					Hytrel® RS 40F2 NC010	Hytrel® RS 40F3 NC010	Hytrel® RS 40F5 NC010	Hytrel® RS 55F5 NC010	Hytrel® RS 63F5 NC010
Rheological	Melt Volume-Flow Rate		ISO 1133	cm^3/10 min	-	20	9	-	-
		Temperature		°C	-	220	220	-	-
		Load		kg	-	2.16	2.16	-	-
	Melt Mass-Flow Rate		ISO 1133	g/10 min	-	20	9	-	-
		Temperature		°C	-	220	220	-	-
		Load		kg	-	2.16	2.16	-	-
	Molding Shrinkage	Parallel	ISO 294-4	%	0.2	0.8	0.9	1.3	1.4
		Normal			0.4	0.6	0.7	1.3	1.4
Mechanical	Stress at Break		ISO 527-1/-2	MPa	25	26	25	40	42
				kpsi	3.6	3.8	3.6	5.8	6.1
	Stress at	5% Strain	ISO 527-1/-2	MPa	-	2.1	2.1	-	-
				kpsi	-	0.3	0.3	-	-
		10% Strain		MPa	4	3.3	3.5	11	14
				kpsi	0.6	0.5	0.5	1.6	2
		50% Strain		MPa	7	6.5	6.7	-	-
				kpsi	1	0.9	1	-	-
	Strain at Break		ISO 527-1/-2	%	450	>300	>300	480	450
	Nominal Strain at Break		ISO 527-1/-2	%	>50	800	800	-	-
	Tensile Modulus		ISO 527-1/-2	MPa	53	45	45	176	280
				kpsi	7.7	6.5	6.5	25.5	40.6
	Flexural Modulus		ISO 178	MPa	-	50	50	-	-
				kpsi	-	7.3	7.3	-	-
	Tensile Creep Modulus	1h	ISO 899-1	MPa	-	-	-	-	-
				kpsi	-	-	-	-	-
		1000h		MPa	-	-	-	-	-
				kpsi	-	-			
	Charpy Impact Strength	-30°C	ISO 179/1eU	kJ/m^2	-	N	N	-	-
		23°C			-	N	N	-	-
	Charpy Notched Impact Strength	-40°C	ISO 179/1eA	kJ/m^2	-	N	N	-	-
		-30°C			-	N	N	150	-
		23°C			-	N	N	-	-
	Tear Strength	Parallel	ISO 34-1	kN/m	105	97	101	185	190
		Normal			-	99	103	-	-
	Abrasion Resistance		ISO 4649	mm^3	-	200	-	-	-
	Shore D Hardness	15 s	ISO 868		39	33	33	-	-
		max			43	37	37	60	68
Thermal	Melting Temperature		ISO 11357-1/-3	°C	150	190	190	201	210
				°F	302	374	374	394	410
	Glass Transition Temperature, 10°C/min		ISO 11357-1/-2	°C	-	-	-	-	-
				°F	-	-	-	-	-
	Temp. of Deflection under Load	1.8 MPa	ISO 75-1/-2	°C	-	-	-	-	-
				°F	-	-	-	-	-
		0.45 MPa		°C	-	50	50	-	-
				°F	-	122	122		
	Vicat Softening Temperature, 50°C/h, 50N		ISO 306	°C	-	-	-	-	-
				°F	-	-	-	-	-
	CLTE, 23-55°C	Parallel	ISO 11359-1/-2	E-6/°K	-	210	210	-	-
				E-6/°F	-	117	117	-	-
		Normal		E-6/°K	-	200	200	-	-
				E-6/°F	-	111	111	-	-
Other	Water Absorption, 2mm		ISO 62	%	-	-	-	-	-
	Humidity Absorption, 2mm				-	-	-	-	-
	Water Absorption, Immersion 24h		ASTM D 570	%	-	-	-	-	-
	Density		ISO 1183	g/cm^3	1.16	1.11	1.11	1.19	1.22

Note: 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 for design.
[P] = Partial Break

Section 2 - Mechanical Properties

Tensile Properties

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 2.1 through 2.38**. 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. Generally, the stiffer grades of Hytrel® show higher tensile strength and lower elongation than the softer grades. The stiffer grades are higher in the crystalline polyester hard segment and therefore behave more like typical engineering plastics.

Yield Stress

The yield stress, also taken from the stress-strain curve, is the point at which the material continues to elongate (strain) without additional stress. The yield stress 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.

Figure 2.1 Hytrel® 3078, High Strain

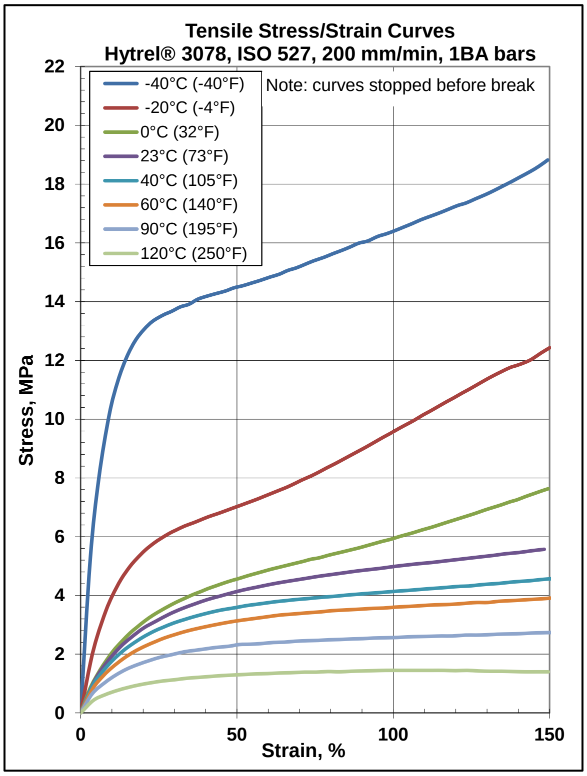


Figure 2.3 Hytrel® 4056, High Strain

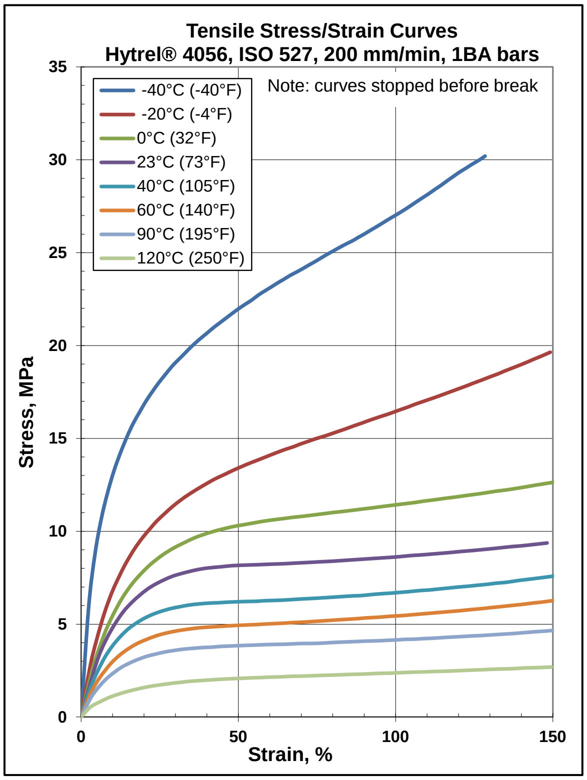


Figure 2.2 Hytrel® 3078, Low Strain

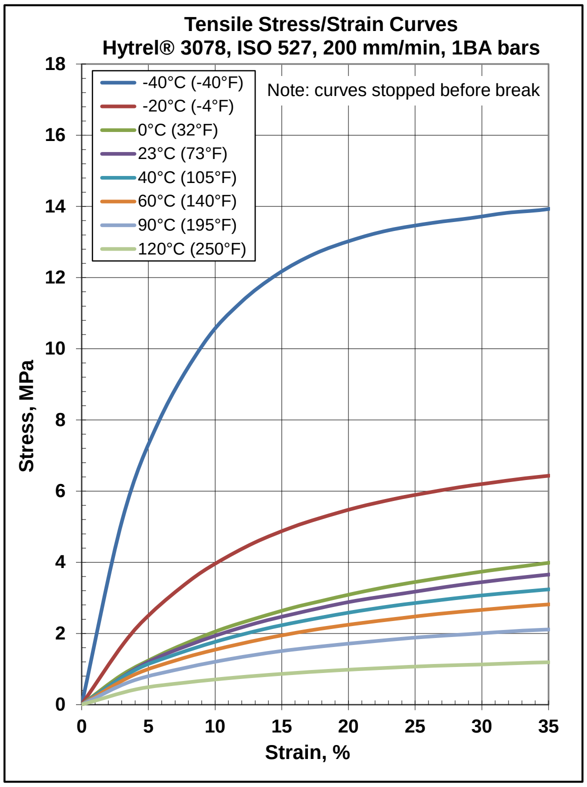


Figure 2.4 Hytrel® 4056, Low Strain

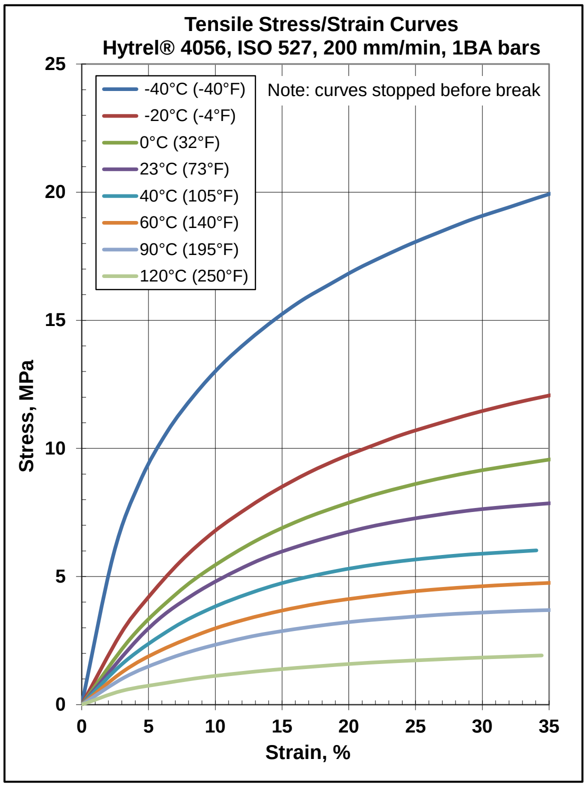


Figure 2.5 Hytrel® 4068, High Strain

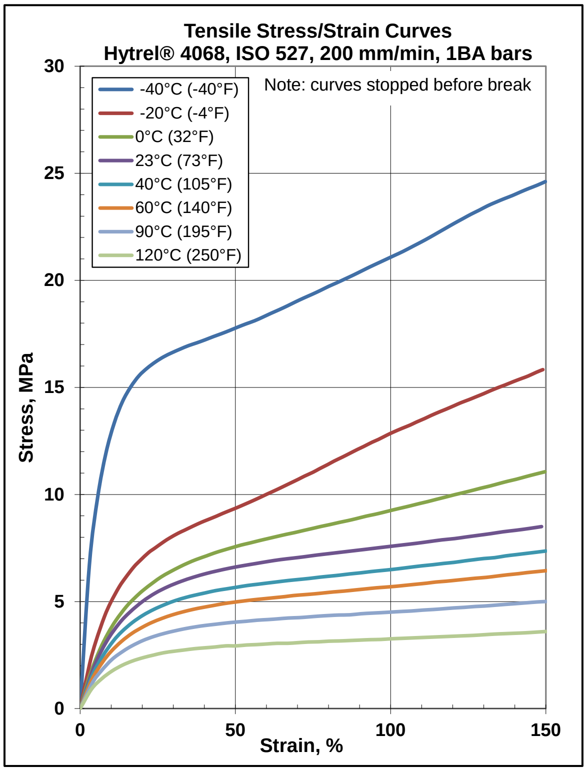


Figure 2.7 Hytrel® 4556, High Strain

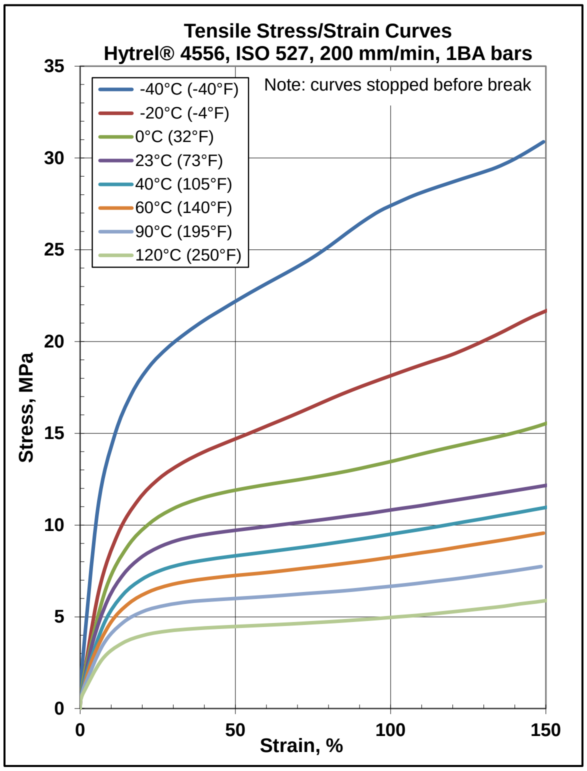


Figure 2.6 Hytrel® 4068, Low Strain

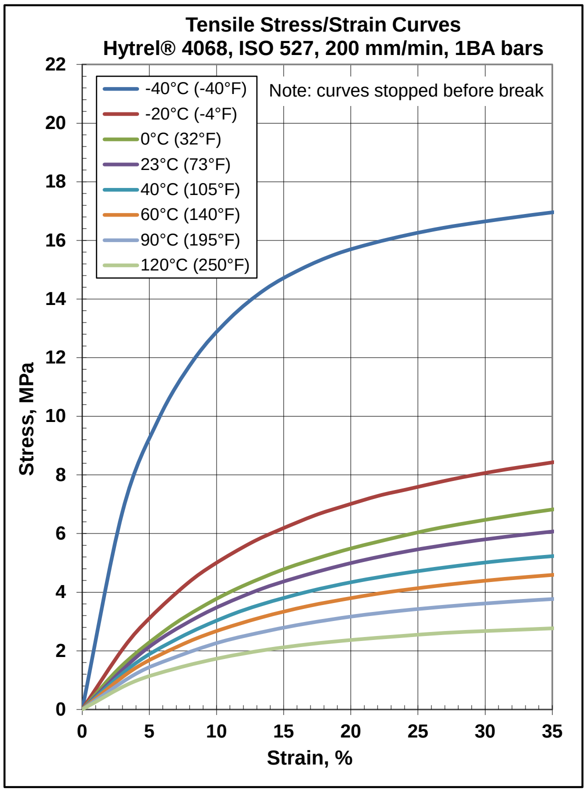


Figure 2.8 Hytrel® 4556, Low Strain

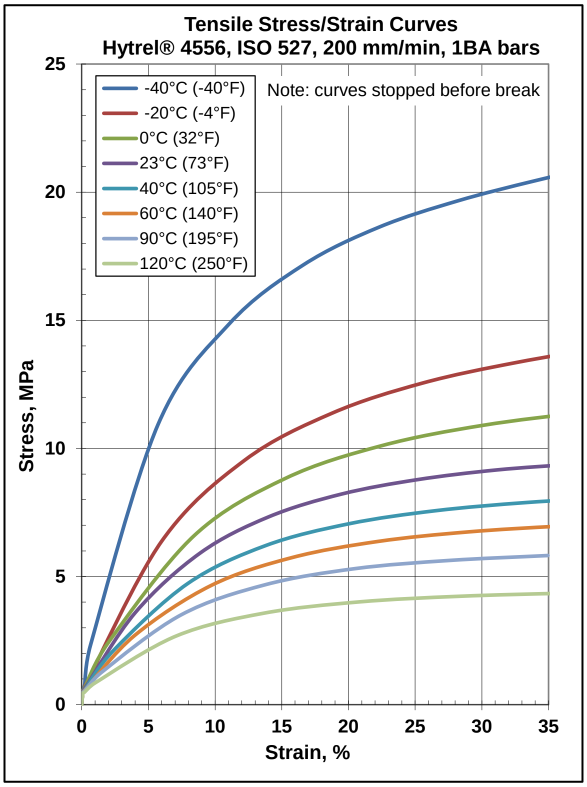


Figure 2.9 Hytrel® 5526, High Strain

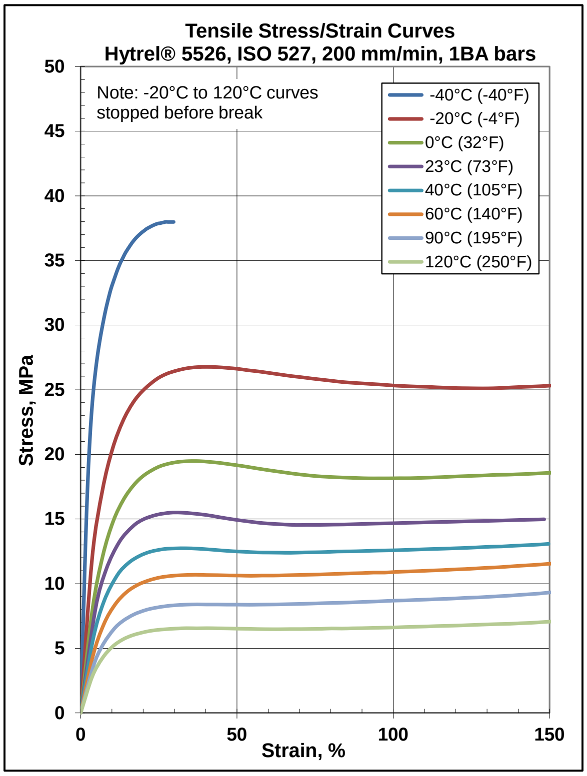


Figure 2.11 Hytrel® 5555HS, High Strain

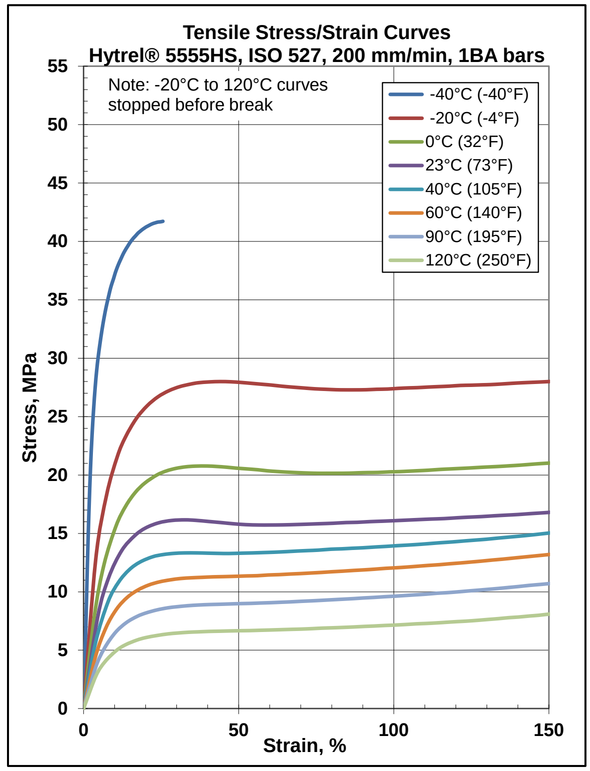


Figure 2.10 Hytrel® 5526, Low Strain

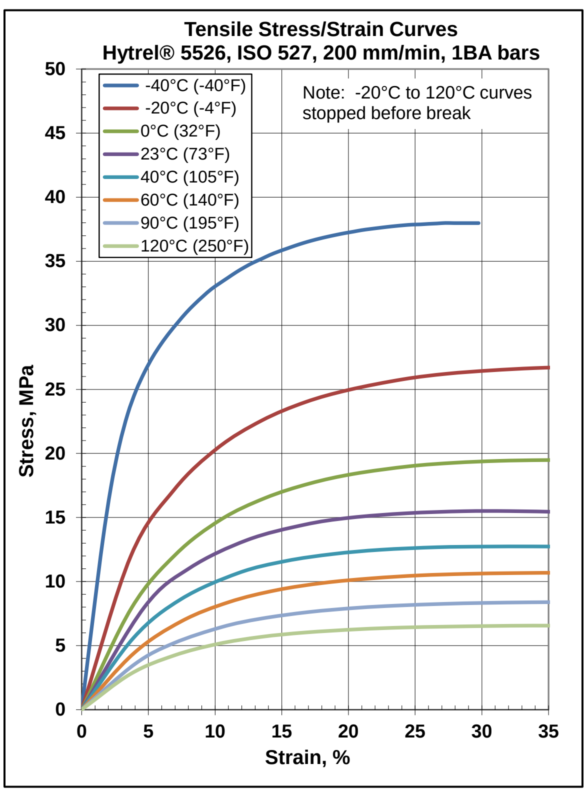


Figure 2.12 Hytrel® 5555HS, Low Strain

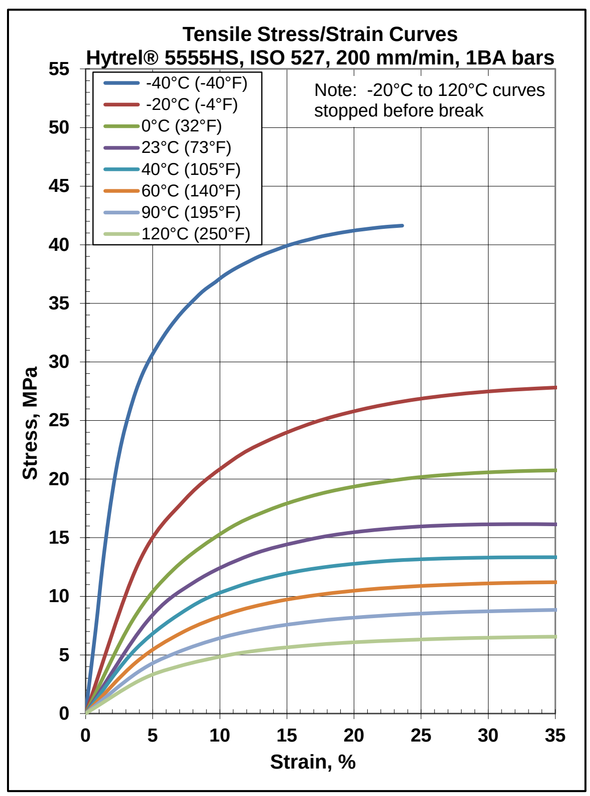


Figure 2.13 Hytrel® 5556, High Strain

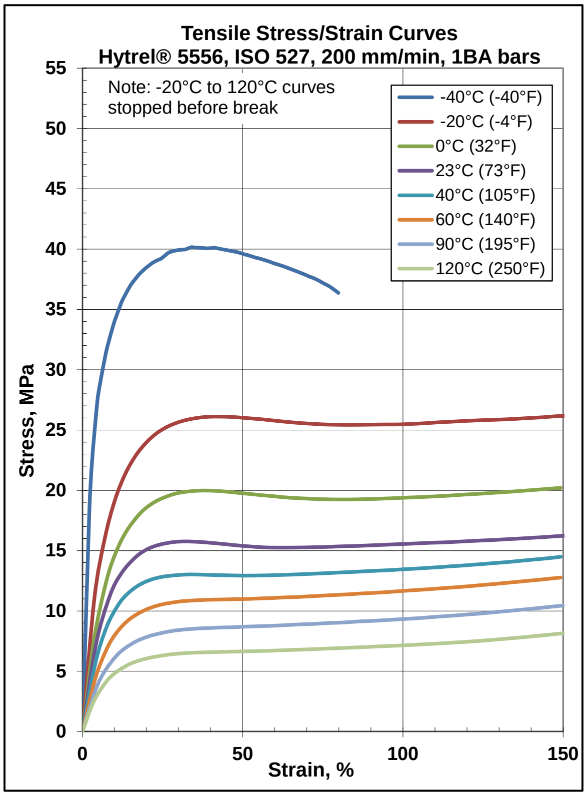


Figure 2.15 Hytrel® 6356, High Strain

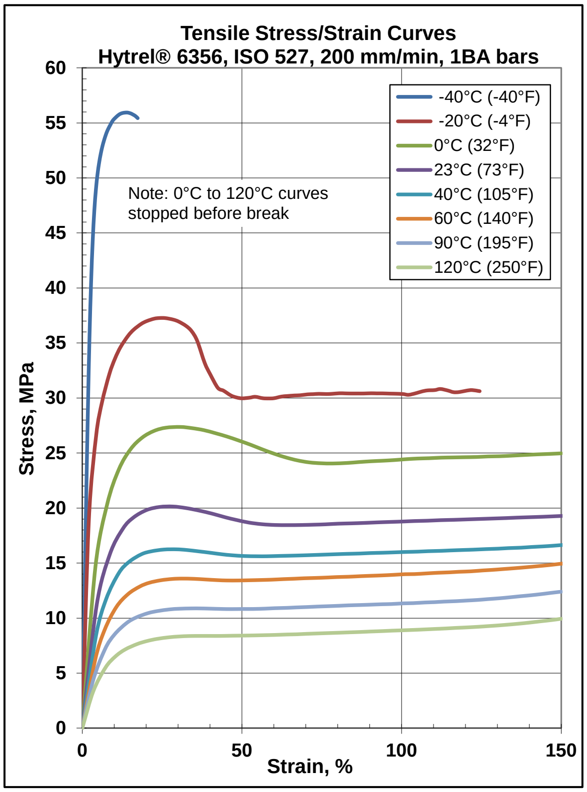


Figure 2.14 Hytrel® 5556, Low Strain

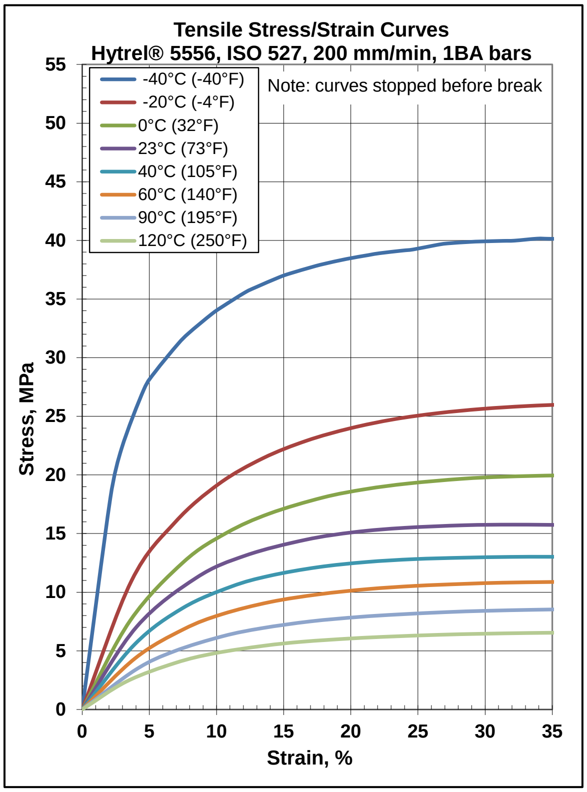


Figure 2.16 Hytrel® 6356, Low Strain

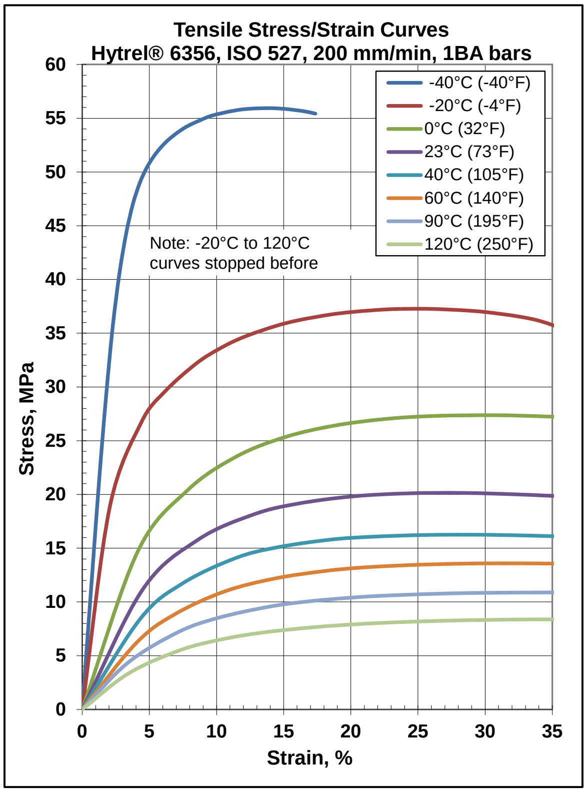


Figure 2.17 Hytrel® 7246, High Strain

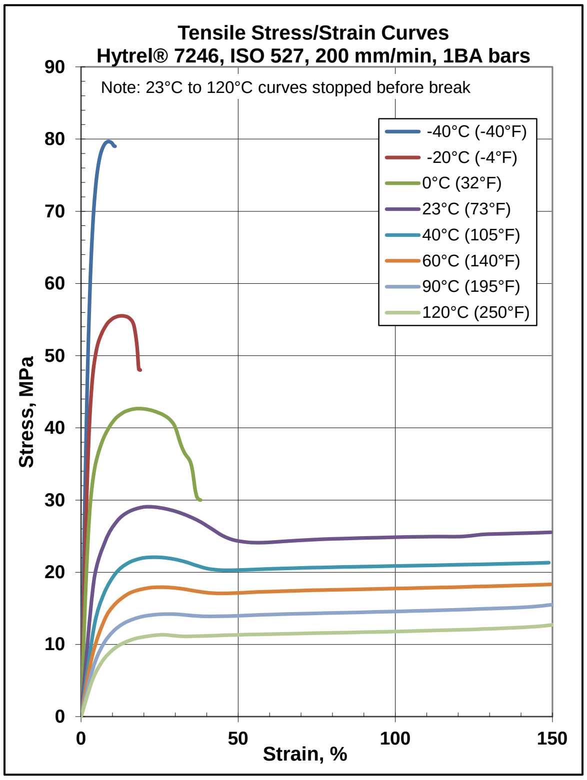


Figure 2.18 Hytrel® 7246, Low Strain

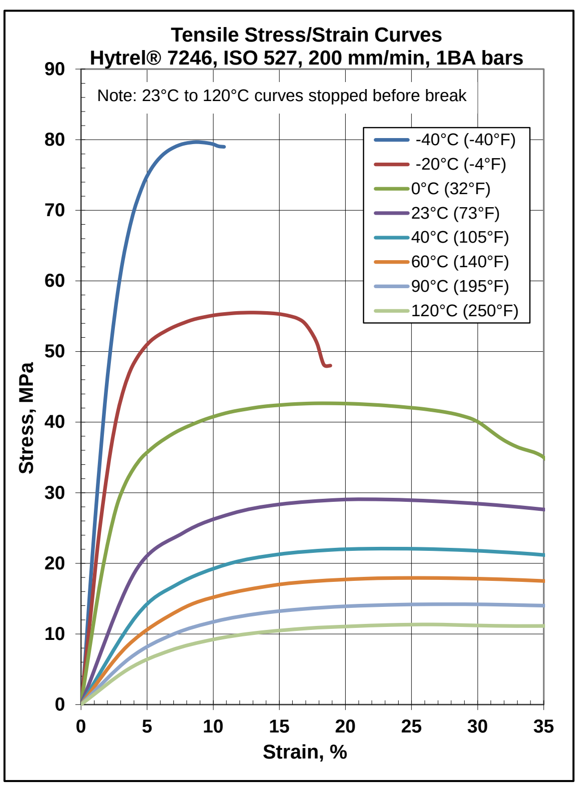


Figure 2.19 Hytrel® 8238, High Strain

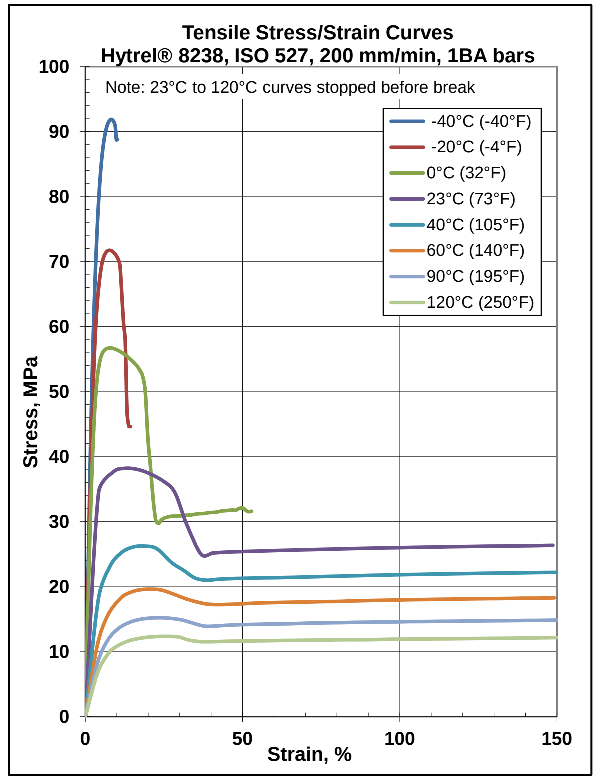


Figure 2.20 Hytrel® 8238, Low Strain

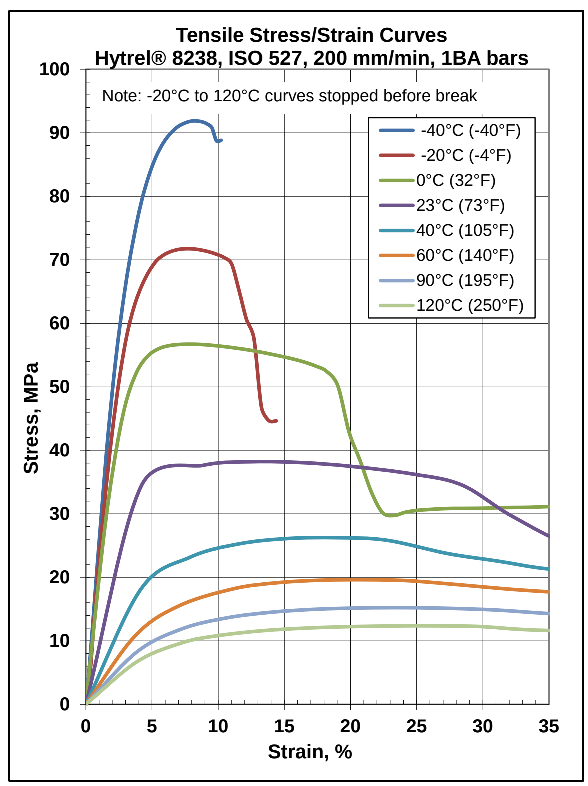


Figure 2.21 Hytrel® G3548, High Strain

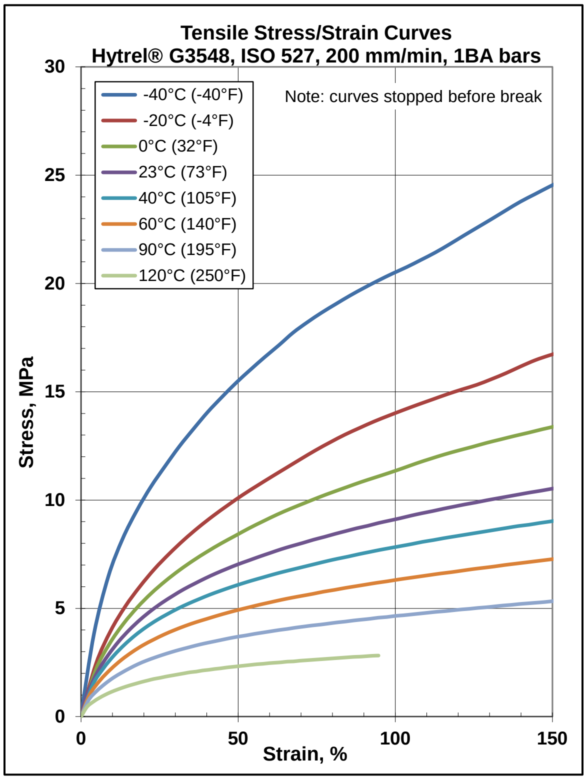


Figure 2.23 Hytrel® G4074, High Strain

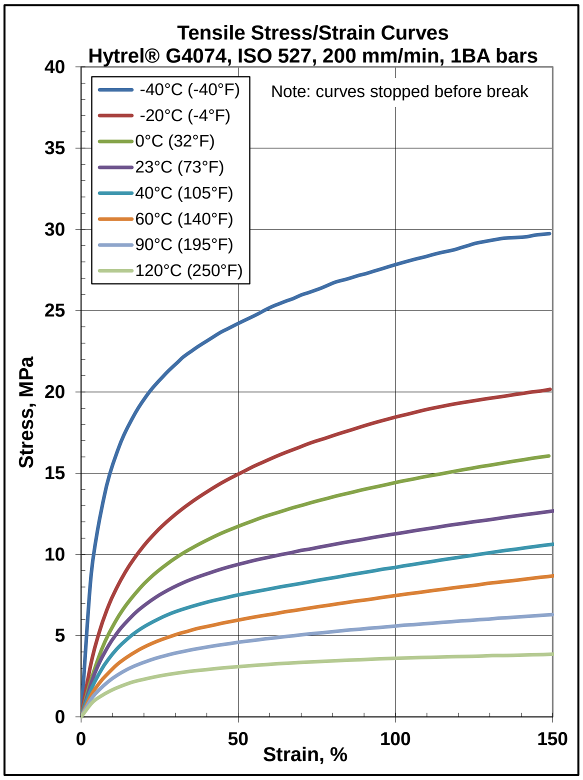


Figure 2.22 Hytrel® G3548, Low Strain

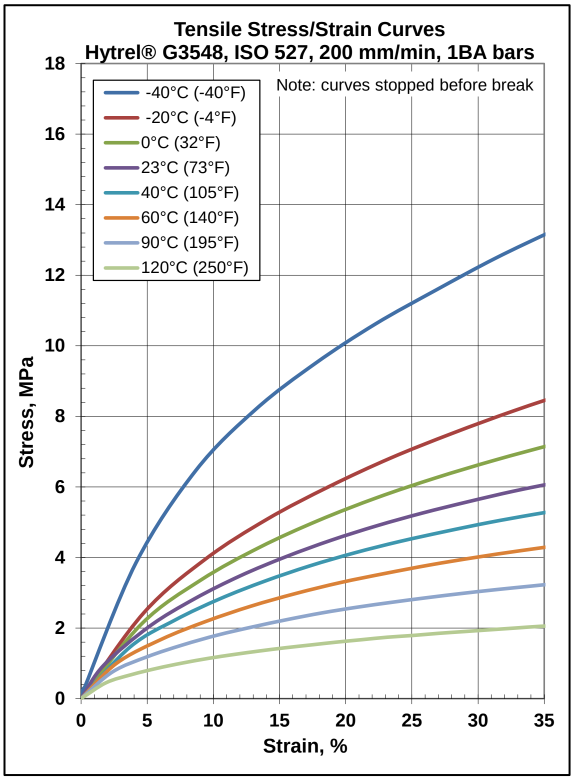


Figure 2.24 Hytrel® G4074, Low Strain

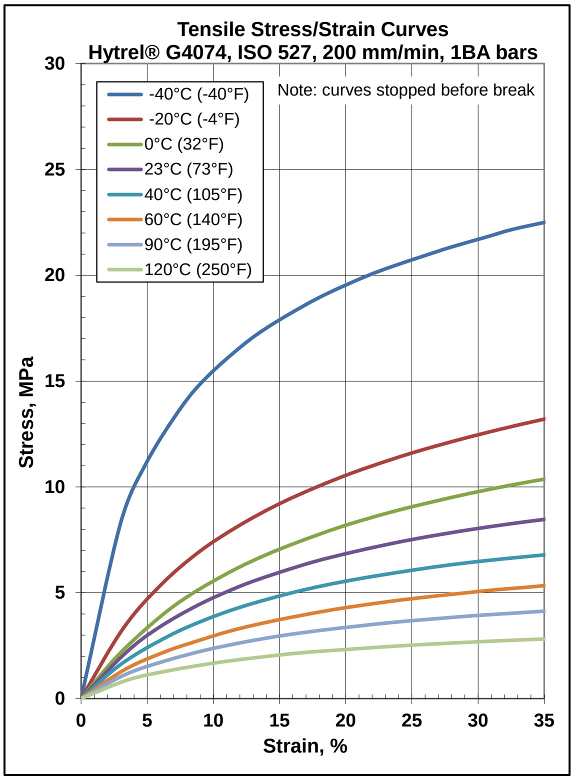


Figure 2.25 Hytrel® G4078, High Strain

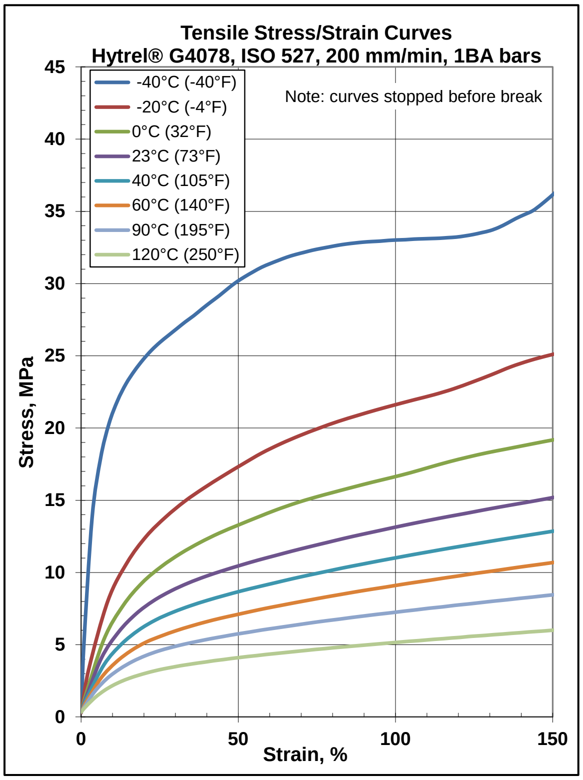


Figure 2.27 Hytrel® G4078LS, High Strain

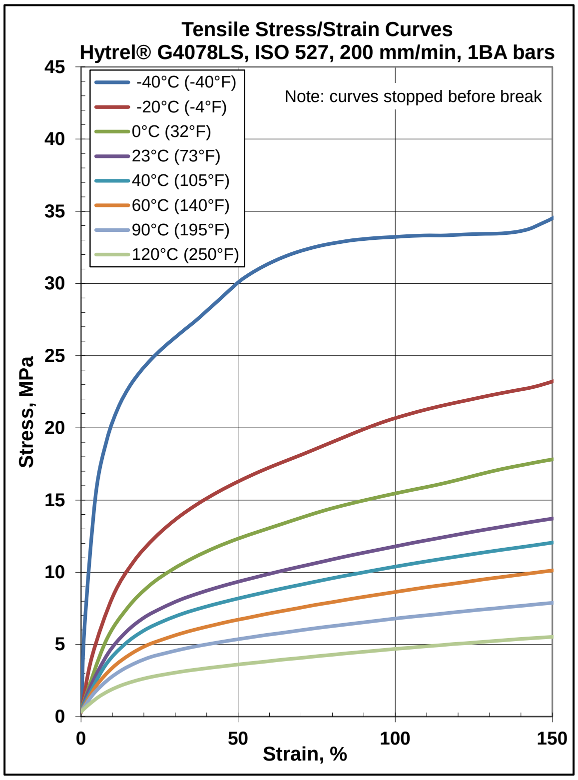


Figure 2.26 Hytrel® G4078, Low Strain

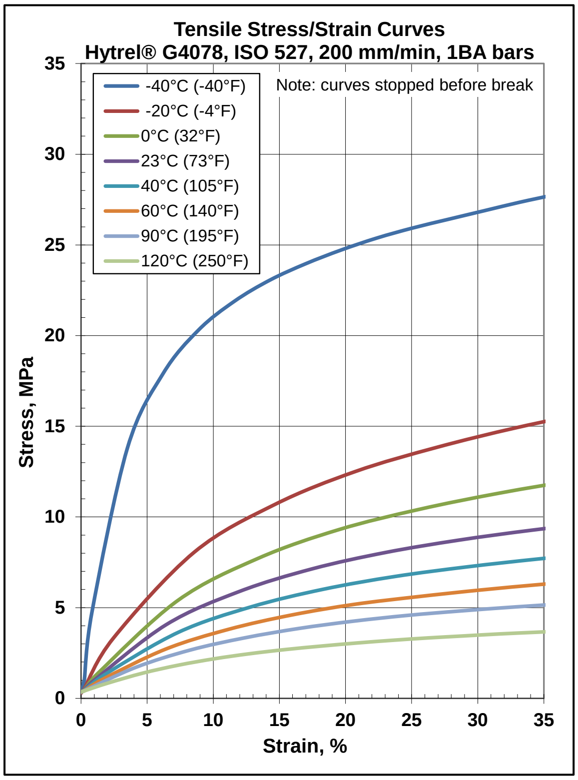


Figure 2.28 Hytrel® G4078LS, Low Strain

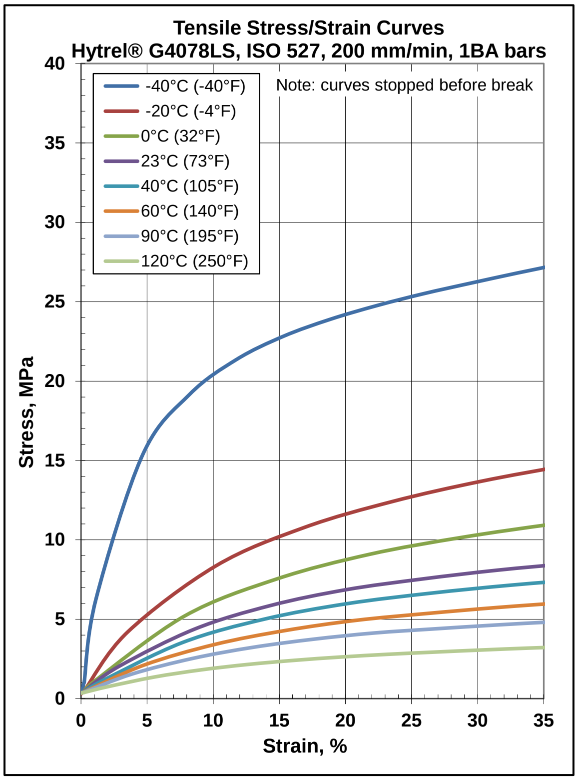


Figure 2.29 Hytrel® G4774, High Strain

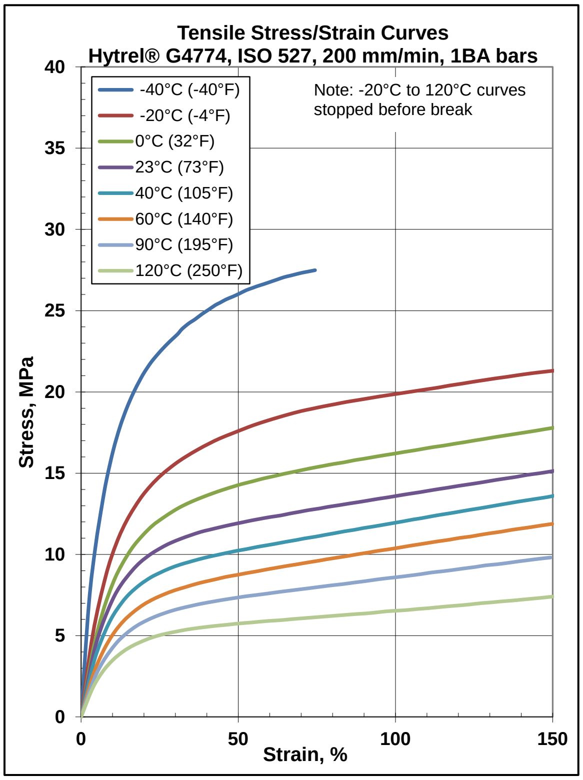


Figure 2.30 Hytrel® G4774, Low Strain

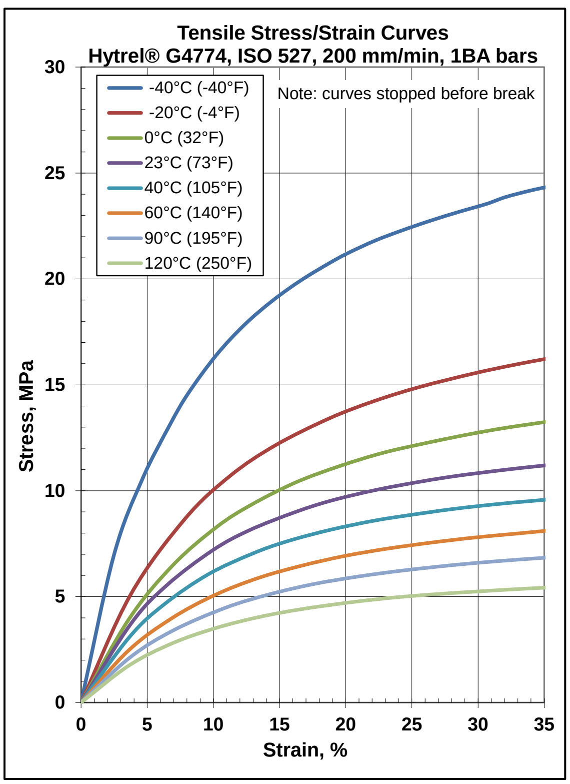


Figure 2.31 Hytrel® G5544, High Strain

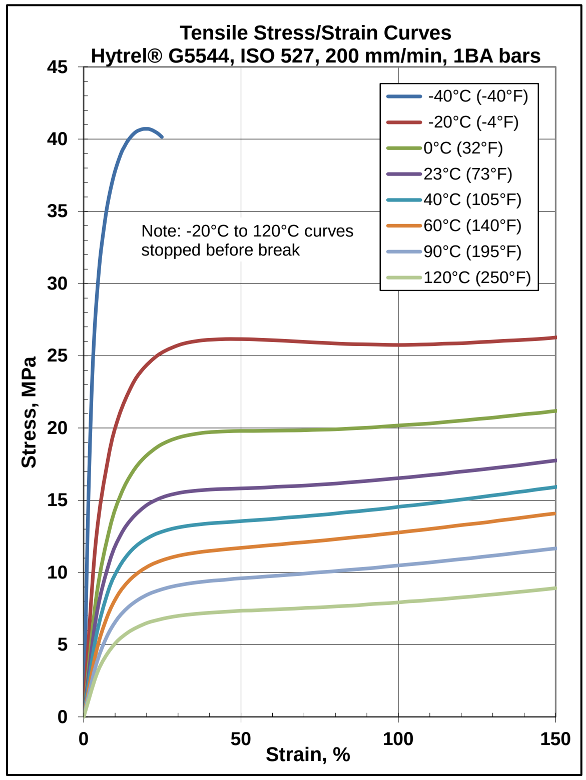


Figure 2.32 Hytrel® G5544, Low Strain

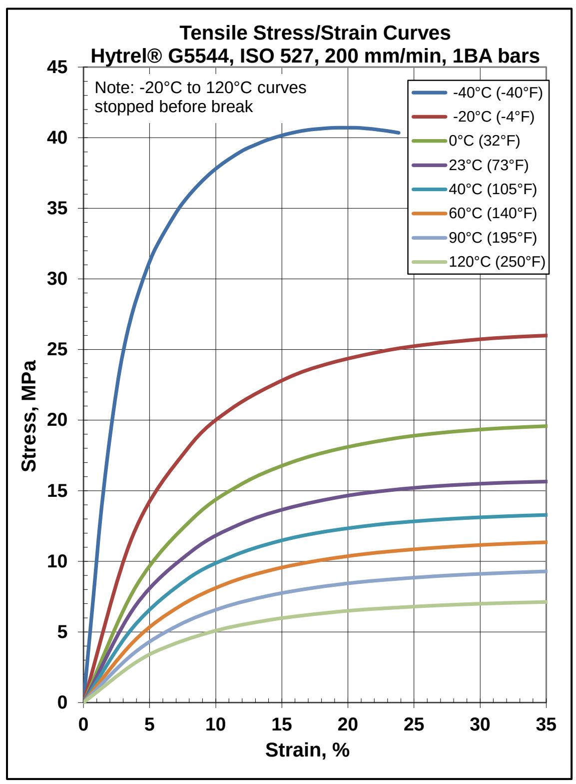


Figure 2.33 Hytrel® HTR4275 BK316, High Strain

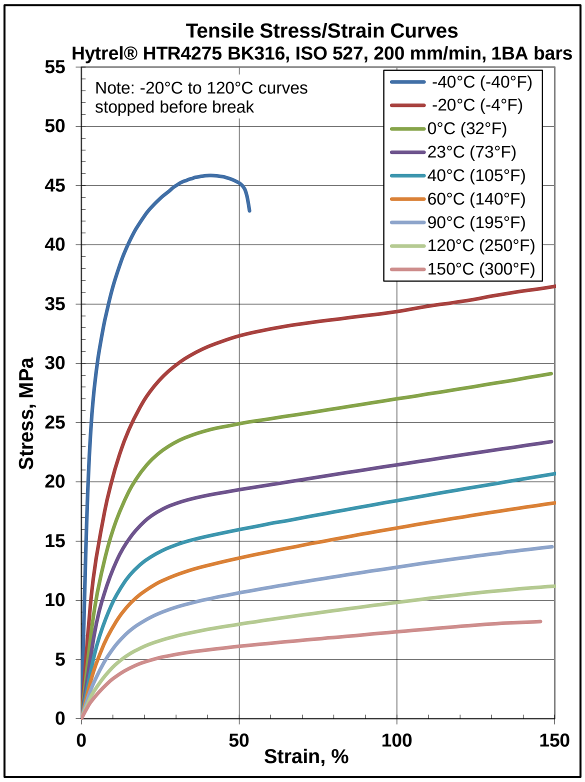


Figure 2.35 Hytrel® HTR8139BK, High Strain

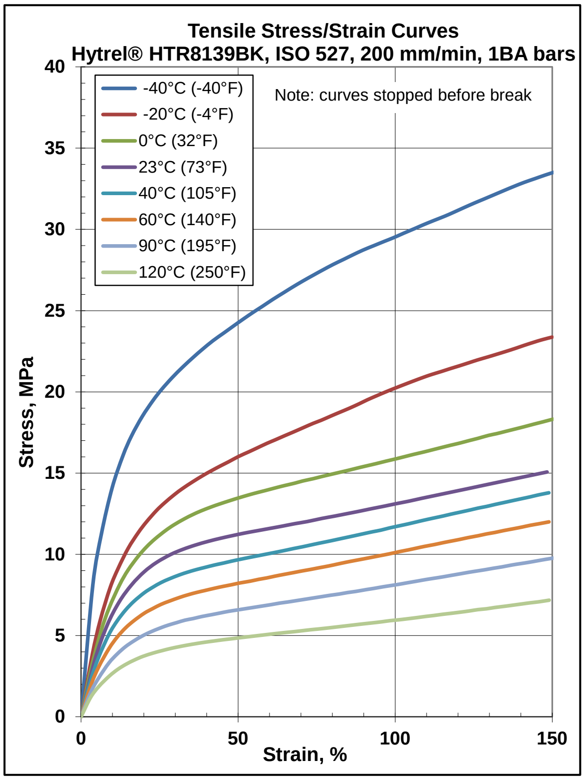


Figure 2.34 Hytrel® HTR4275 BK316, Low Strain

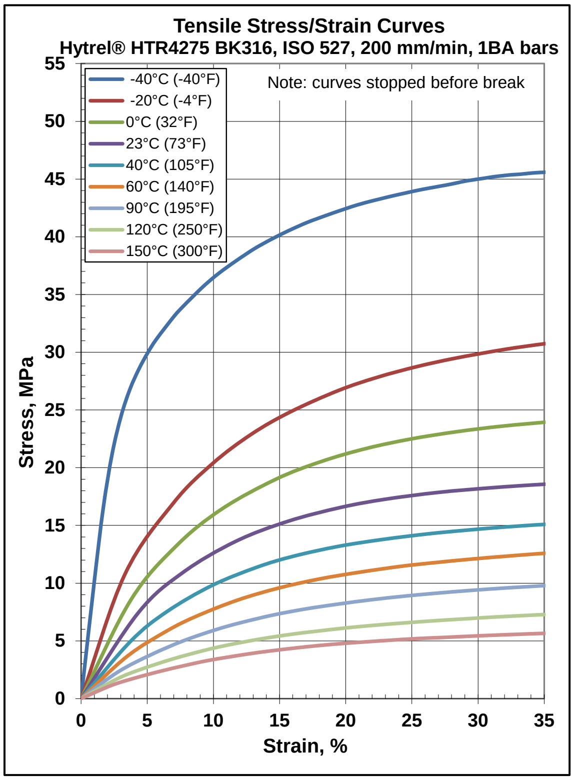


Figure 2.36 Hytrel® HTR8139BK, Low Strain

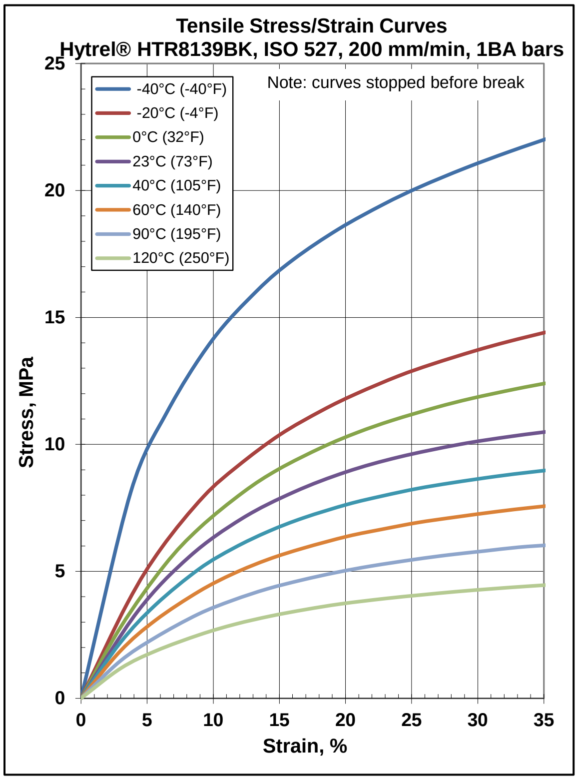


Figure 2.37 Hytrel® DYM350BK, High Strain

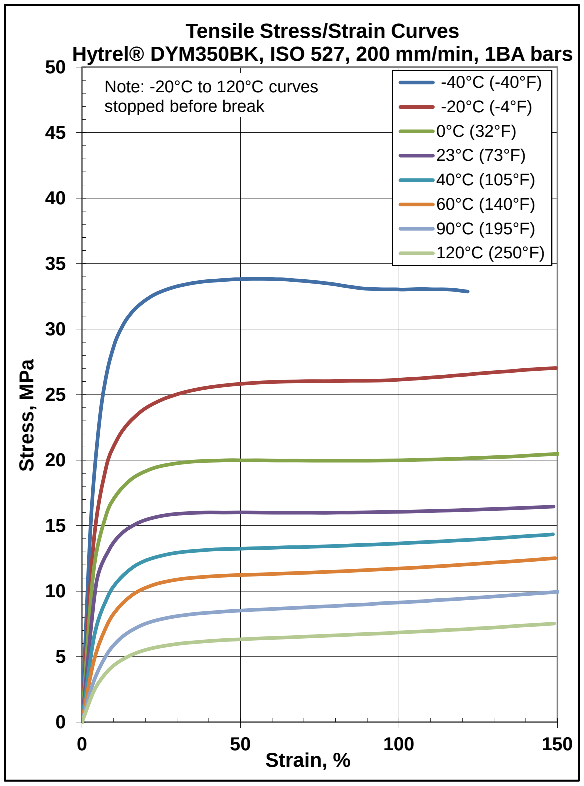
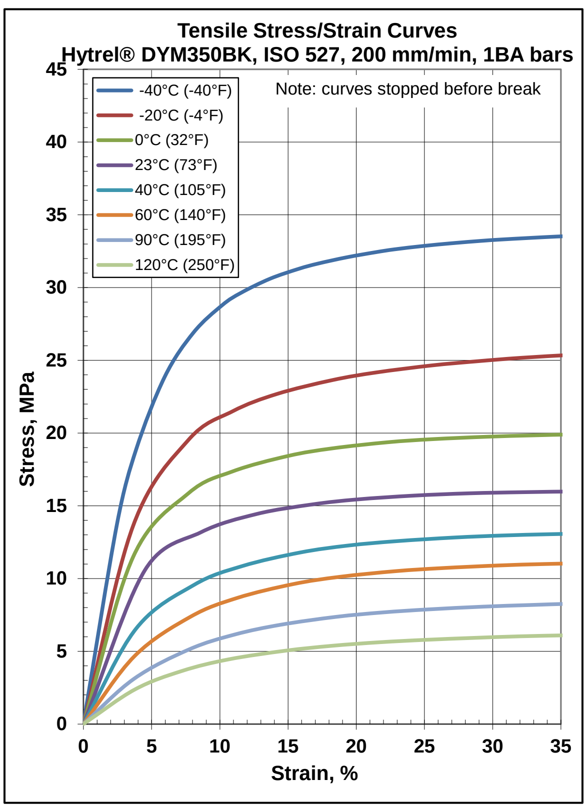


Figure 2.38 Hytrel® DYM350BK, Low Strain



Elastic Modulus in Tension

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 2.39**.

Tensile Set

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 2.40 and 2.41**.

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.

Figure 2.39 Elastic Modulus in Tension vs. Temperature

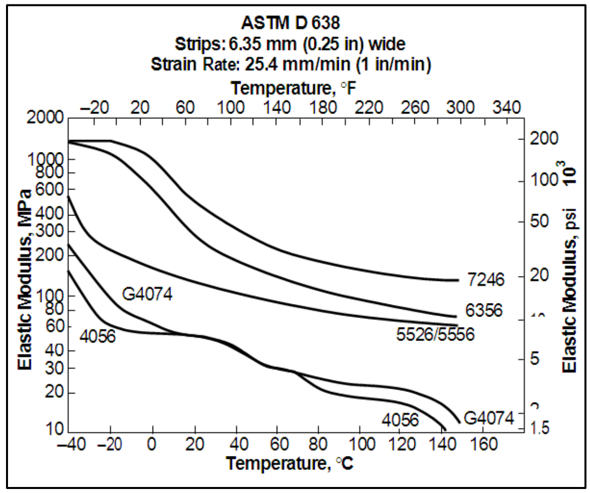


Figure 2.40 Tensile Set

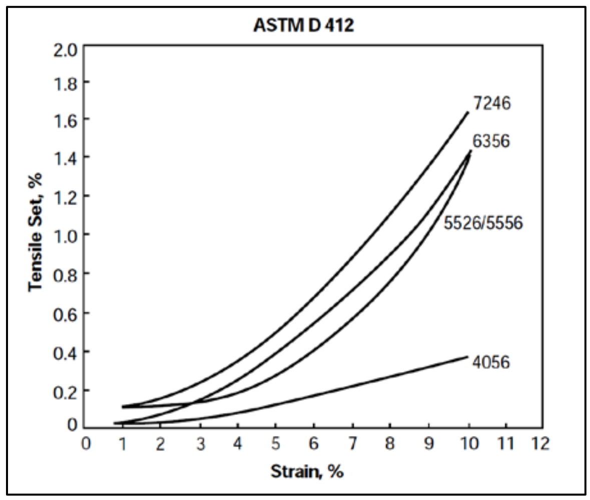
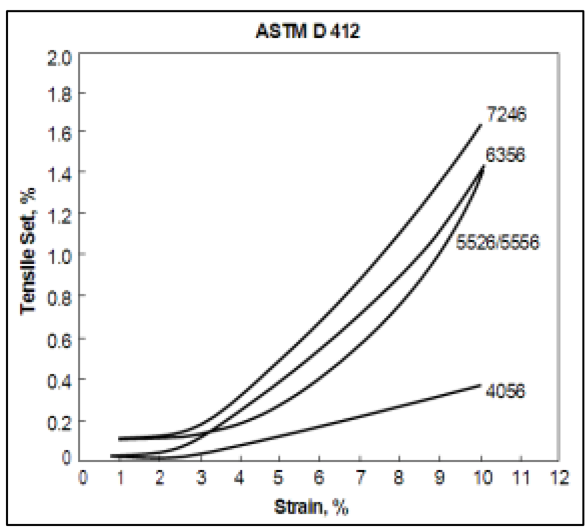


Figure 2.41 Tensile Set at Low Strain



Compressive Properties

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.

Compression Set is a test that can be performed using constant force (ASTM D395 Method A) or constant deflection (ASTM D395 Method B). **Table 2.1** lists the compression set values at different temperatures. Compression set can be significantly improved by annealing.

Table 2.1 Compression Set Resistance

		Compression Set Resistance		
		ASTM D395 Method A, 9.3 MPa (1350 psi)		ASTM D395 Method B
		22 hr at 23°C	22 hr at 70°C	22 hr at 70°C
Hytrel® 3078	As-Molded	23	62	65
	Annealed	21	38	37
Hytrel® 4069	As-Molded	27	54	
	Annealed	27	29	
Hytrel® 4556	As-Molded			56
	Annealed			43
Hytrel® 5556	As-Molded	38	56	56
	Annealed	35	42	47
Hytrel® 6356	As-Molded			51
	Annealed			38
Hytrel® 7246	As-Molded			52
	Annealed			44
Hytrel® G4774	As-Molded			44
	Annealed			37
* Annealing = 1 hr at 150C				

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 2.42 through 2.46** illustrate the compressive stress/strain properties generated by the use of this method at various temperatures.

Figure 2.42 Compressive Properties - Hytrel® G4074

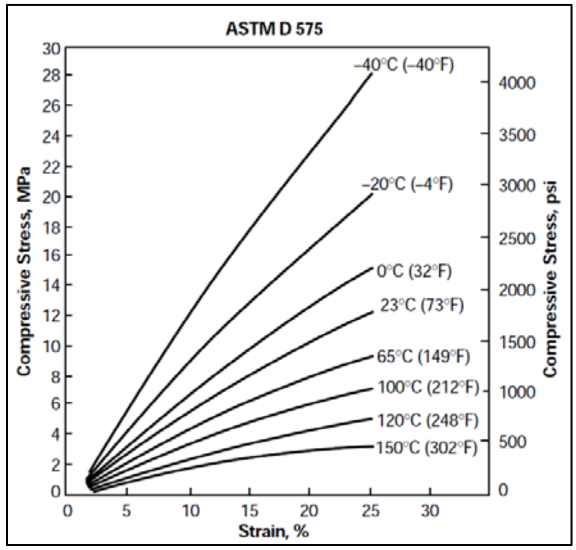


Figure 2.43 Compressive Properties – Hytrel® 4056

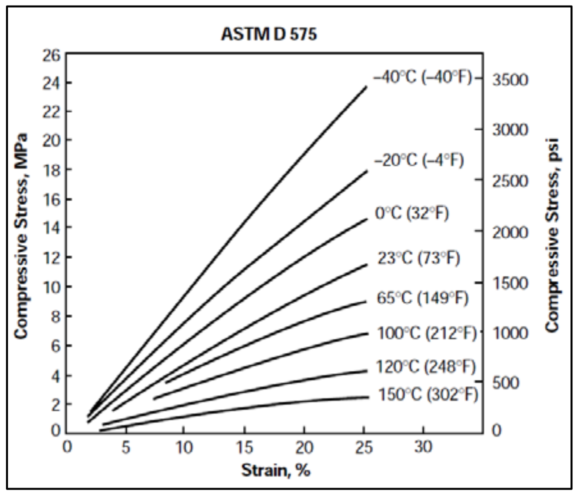


Figure 2.44 Compressive Properties – Hytrel® 5526/5556

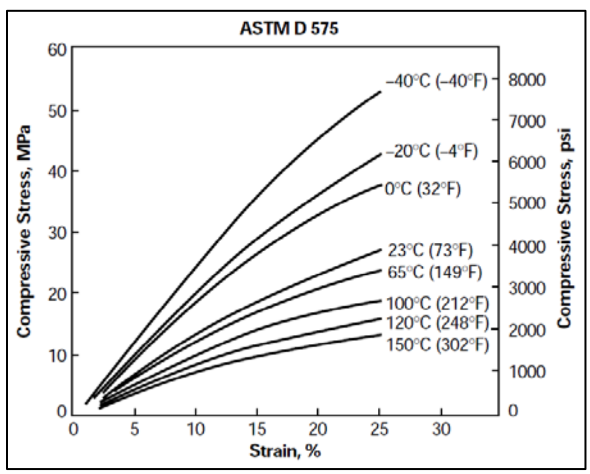


Figure 2.45 Compressive Properties – Hytrel® 6356

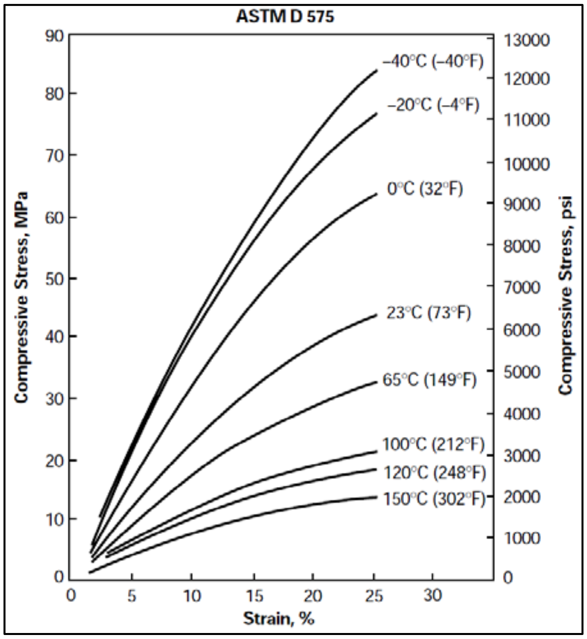
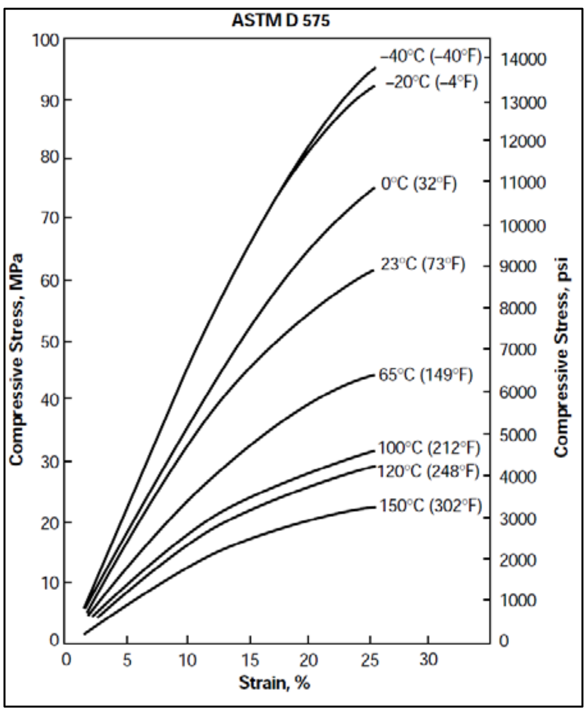


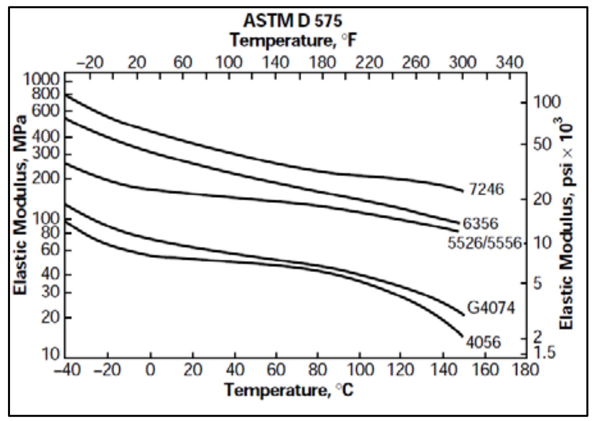
Figure 2.46 Compressive Properties – Hytrel® 7246



Elastic Modulus in Compression

Figure 2.47 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 2.47 Elastic Modulus in Compression vs. Temperature - Hytrel®



Flexural Properties

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 2.48**. 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 and Recovery

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.

Tensile Creep

Figures 2.49 through 2.52 are plots of creep or apparent modulus versus time at various stress levels, all at room temperature. **Figures 2.53 through 2.60** show creep modulus data at 40°C (105°F) and 80°C (175°F). Isochronous stress/strain curves are shown in **Figures 2.61 through 2.72.**

In all cases, testing should be performed on the fabricated part to verify satisfactory performance of the material in each application. For critical applications, testing for the full expected life of the part should be done to verify these results.

Figure 2.48 Flex Modulus vs. Temperature

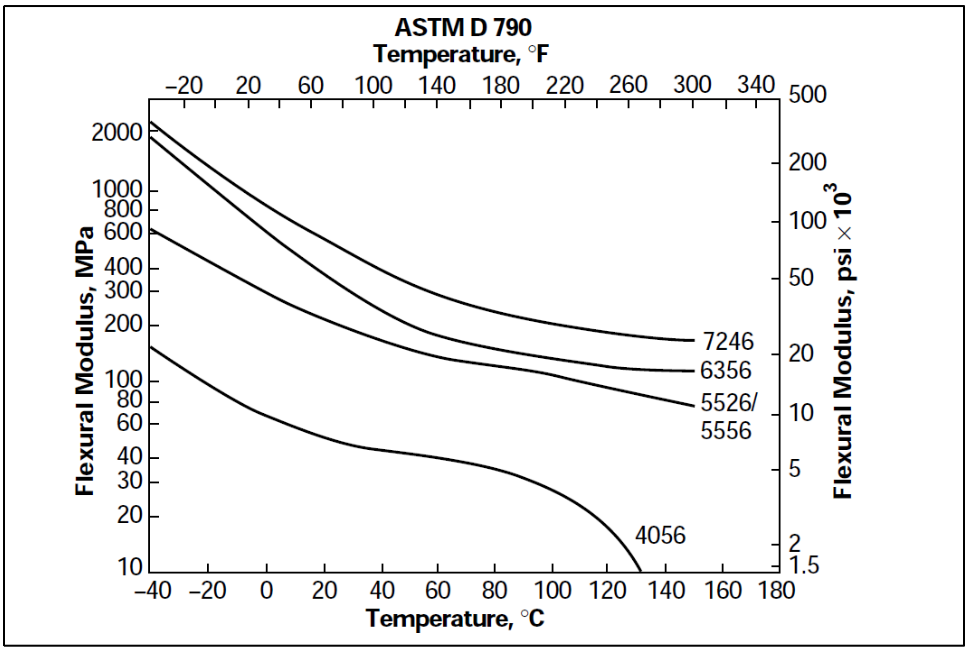


Figure 2.49 Tensile Creep Modulus versus Time for Hytrel® 4056 at 23 °C (73 °F)

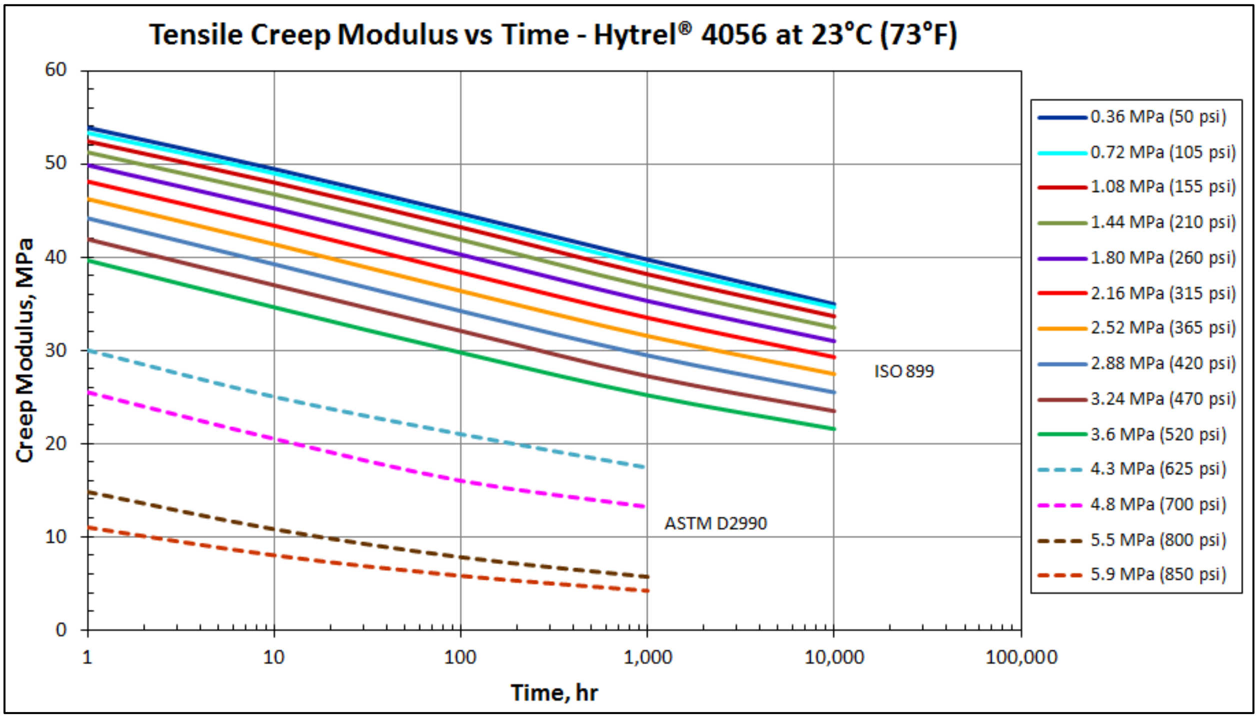


Figure 2.50 Tensile Creep Modulus versus Time for Hytrel® 5556 at 23°C (73°F)

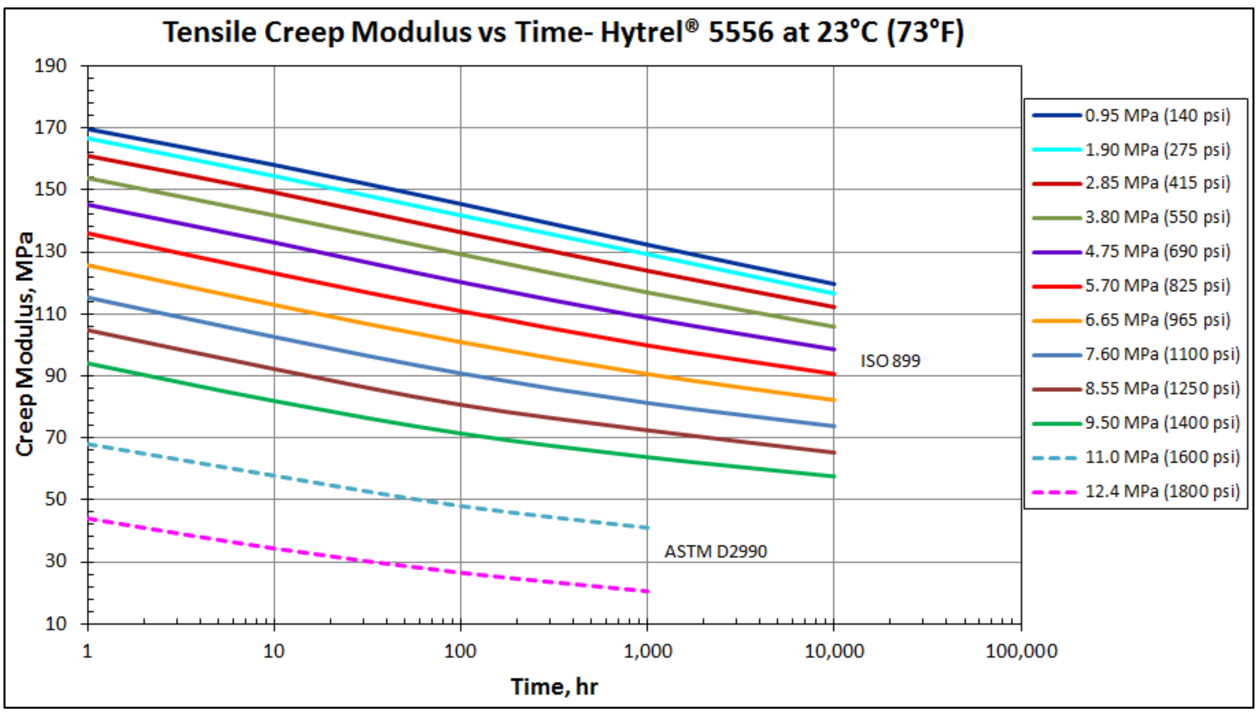


Figure 2.51 Tensile Creep Modulus versus Time for Hytrel® 6356 at 23°C (73°F)

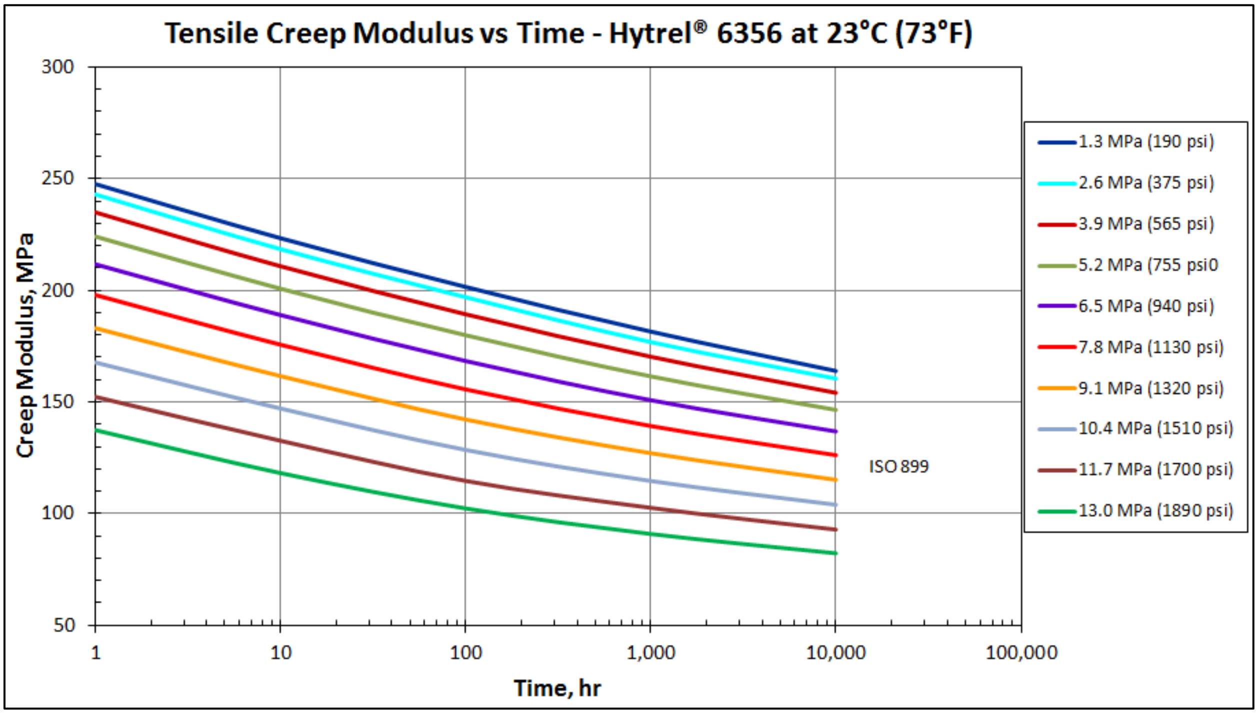


Figure 2.52 Tensile Creep Modulus versus Time for Hytrel® 7246 at 23°C (73°F)

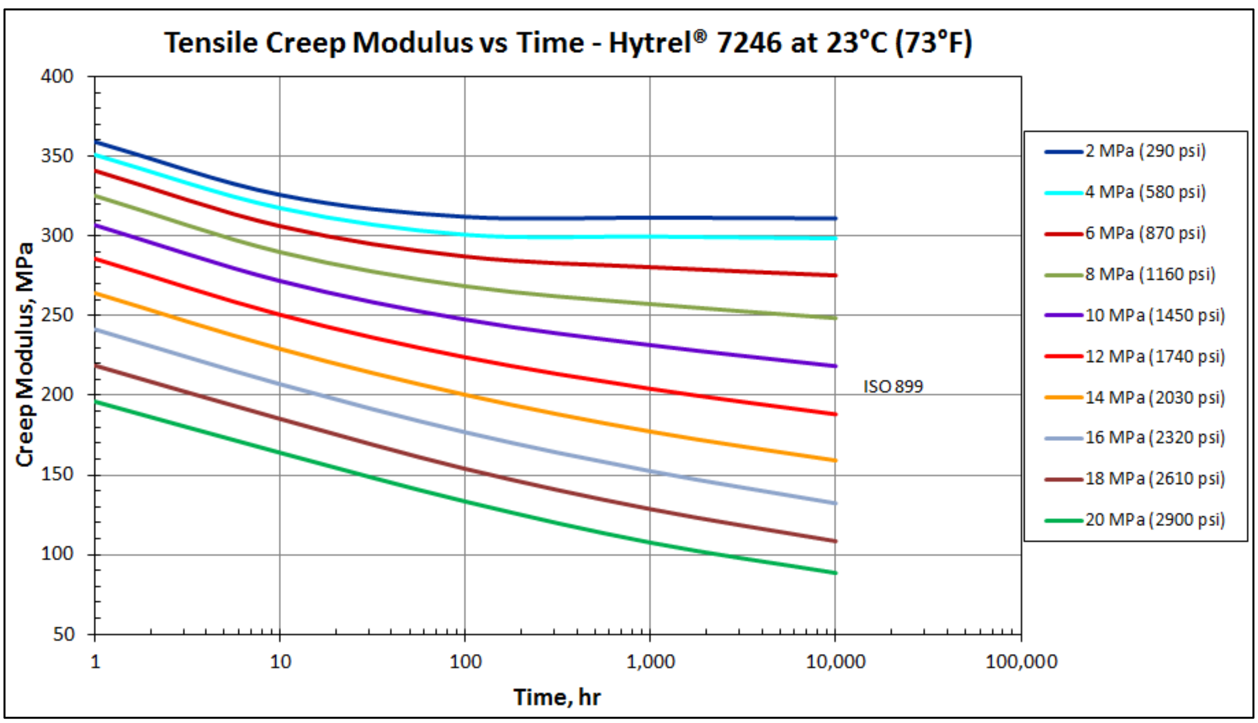


Figure 2.53 Tensile Creep Modulus versus Time for Hytrel® 4056 at 40°C (105°F)

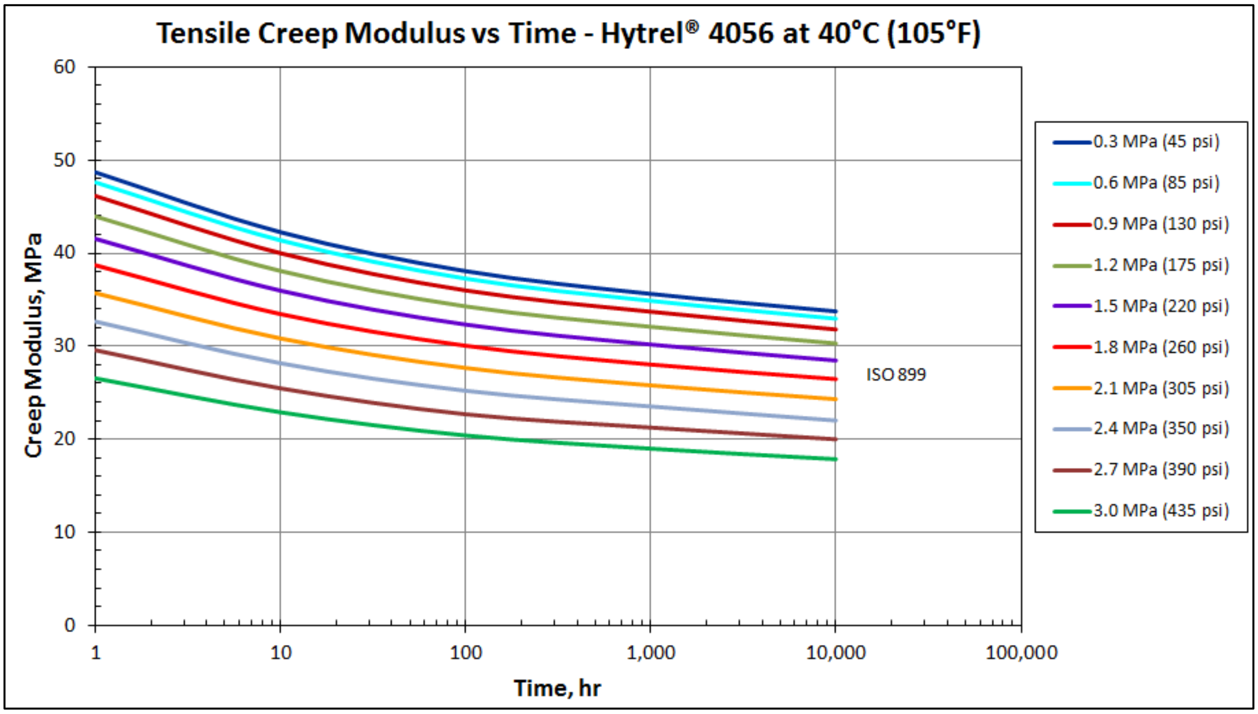


Figure 2.54 Tensile Creep Modulus versus Time for Hytrel® 4056 at 80°C (175°F)

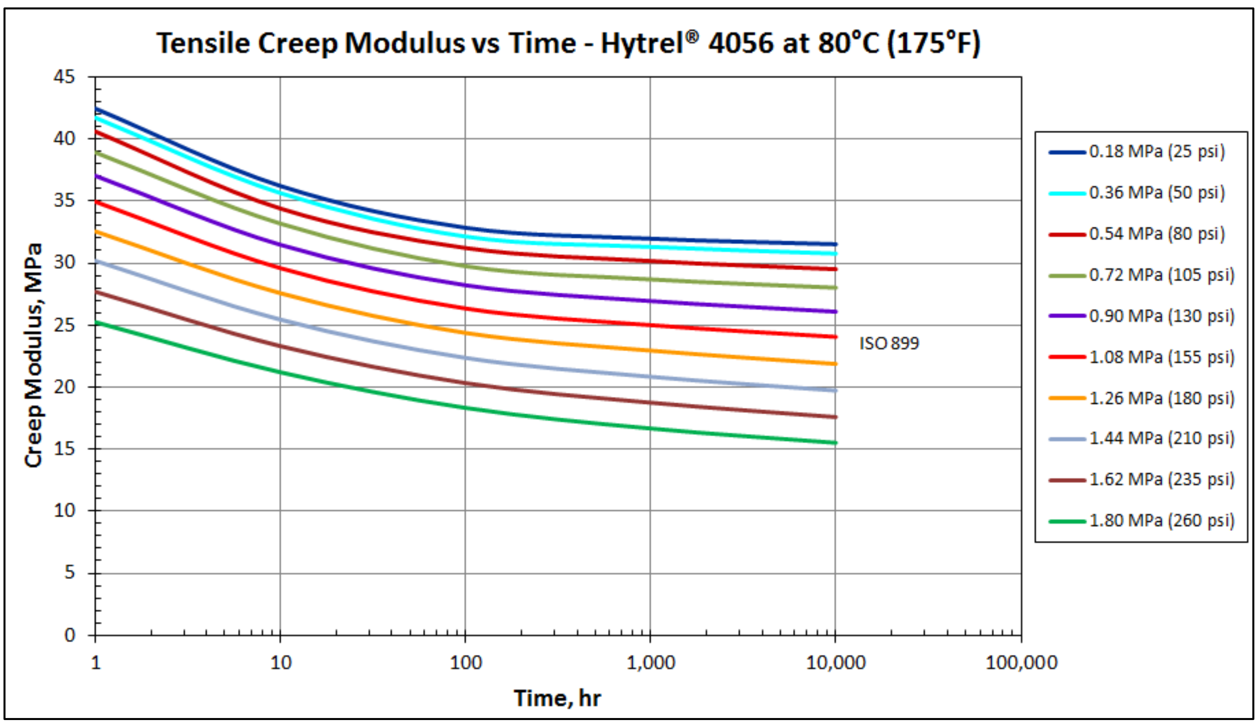


Figure 2.55 Tensile Creep Modulus versus Time for Hytrel® 5556 at 40°C (105°F)

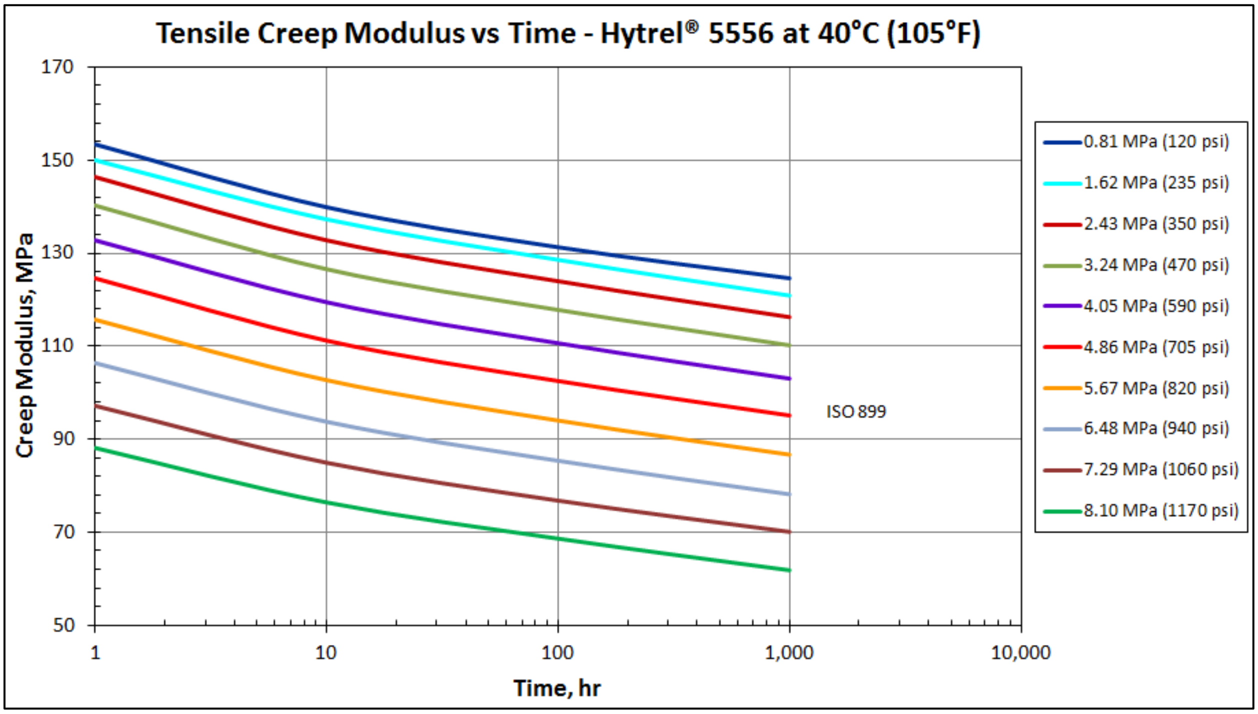


Figure 2.56 Tensile Creep Modulus versus Time for Hytrel® 5556 at 80°C (175°F)

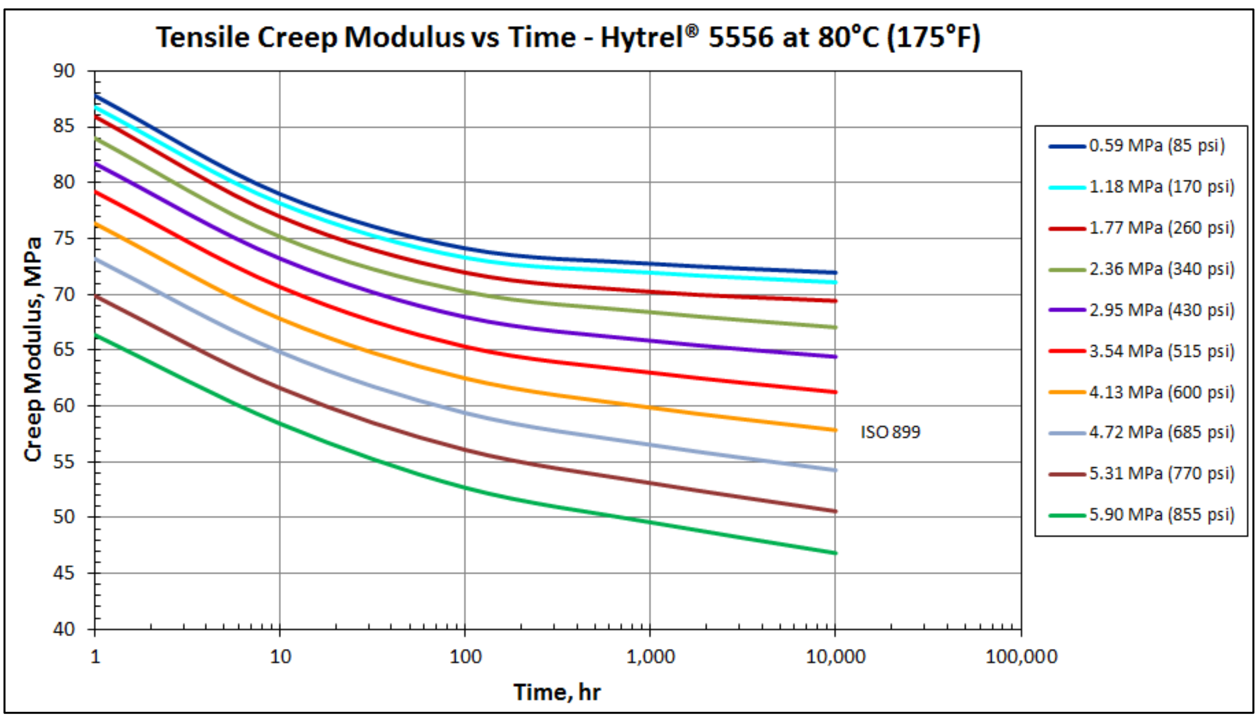


Figure 2.57 Tensile Creep Modulus versus Time for Hytrel® 6356 at 40°C (105°F)

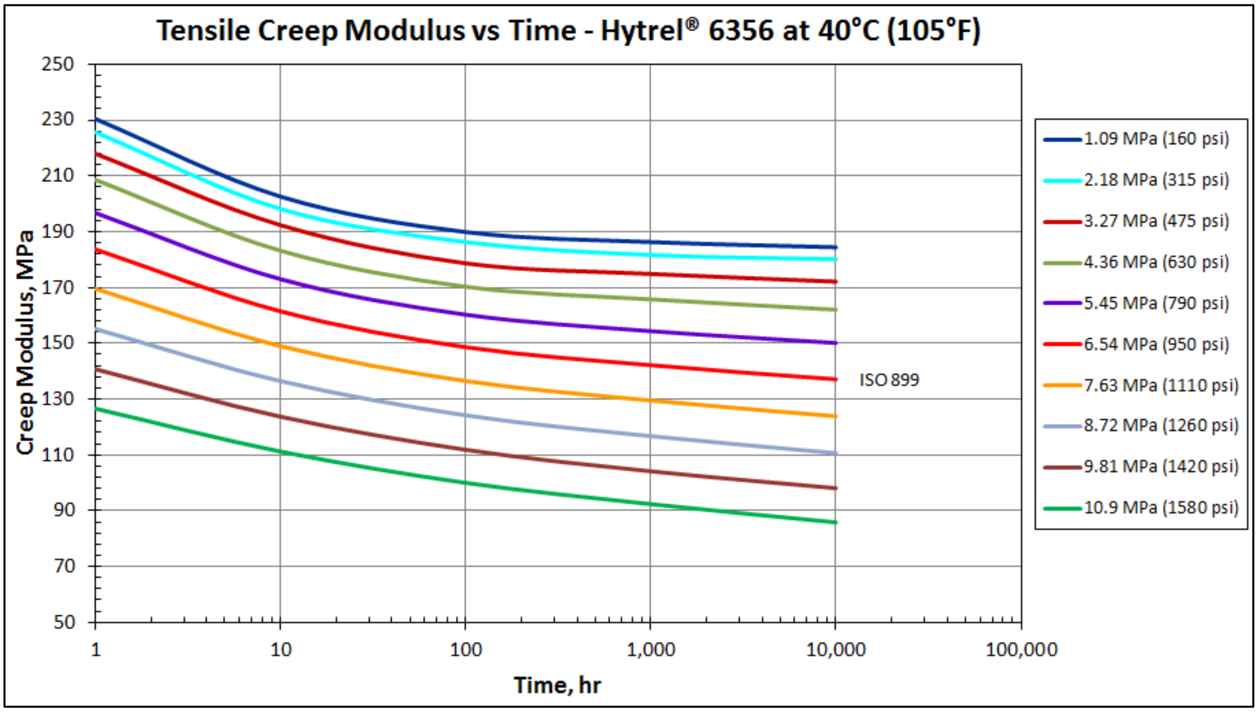


Figure 2.58 Tensile Creep Modulus versus Time for Hytrel® 6356 at 80°C (175°F)

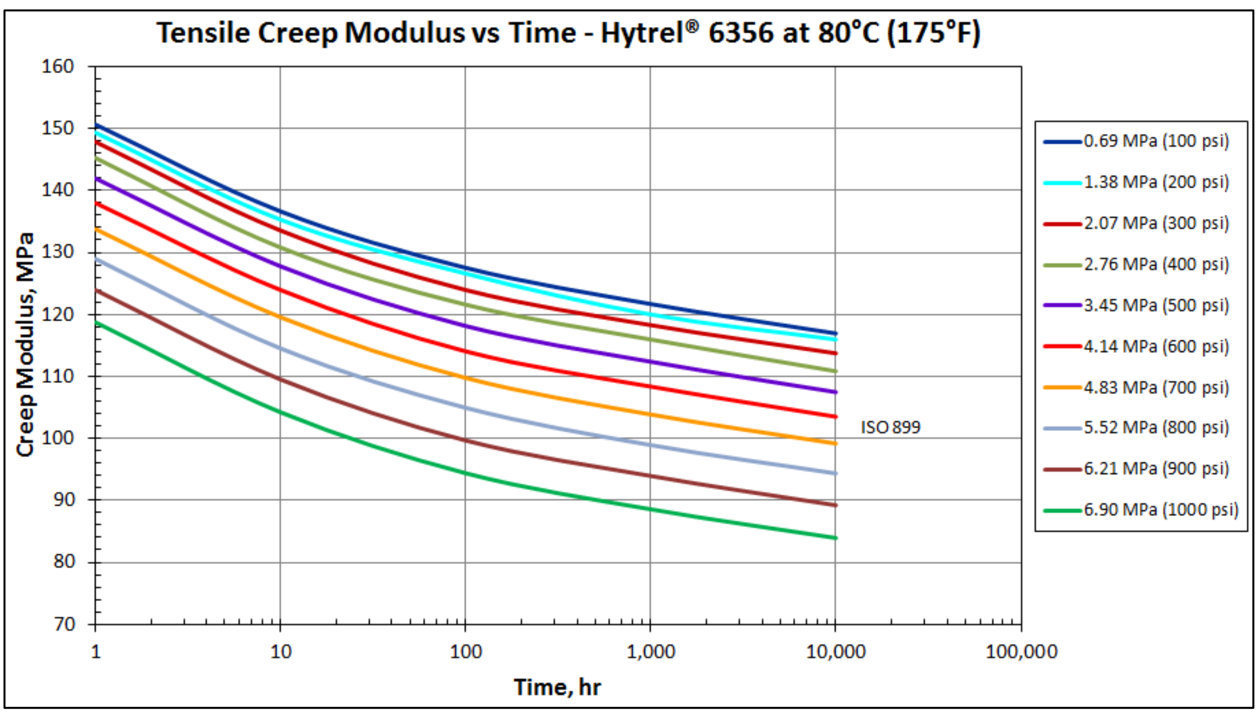


Figure 2.59 Tensile Creep Modulus versus Time for Hytrel® 7246 at 40°C (105°F)

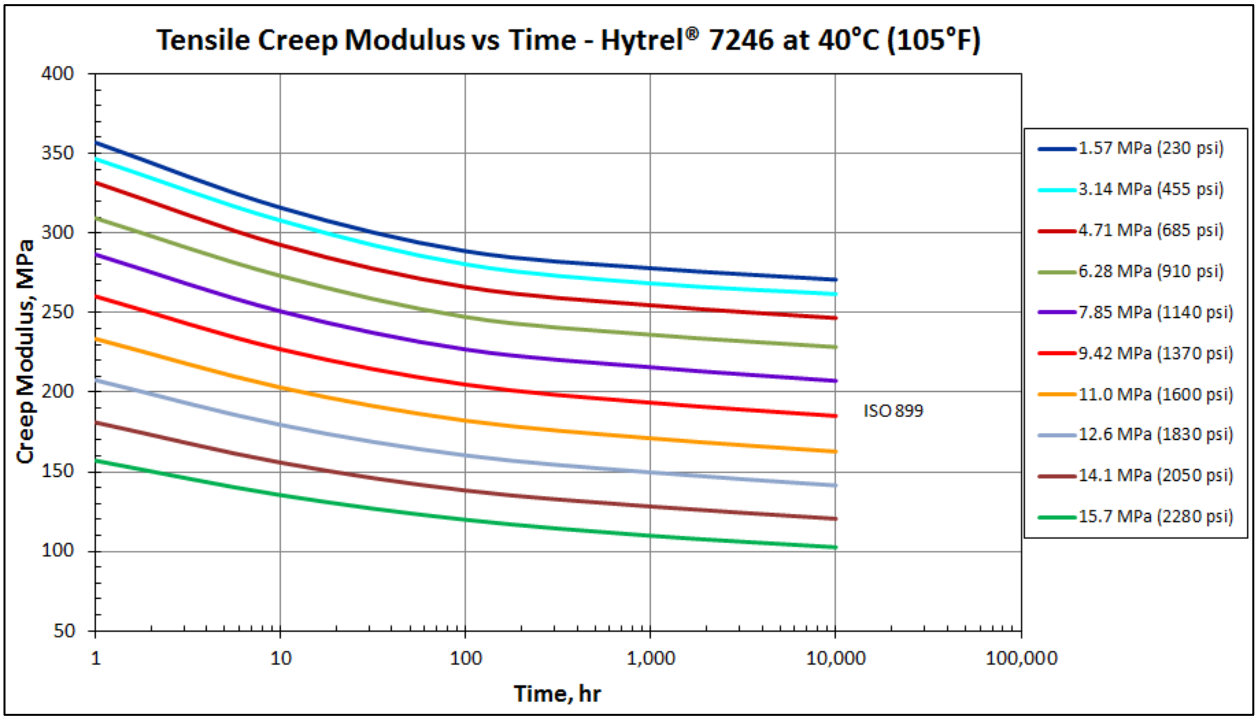


Figure 2.60 Tensile Creep Modulus versus Time for Hytrel® 7246 at 80°C (175°F)

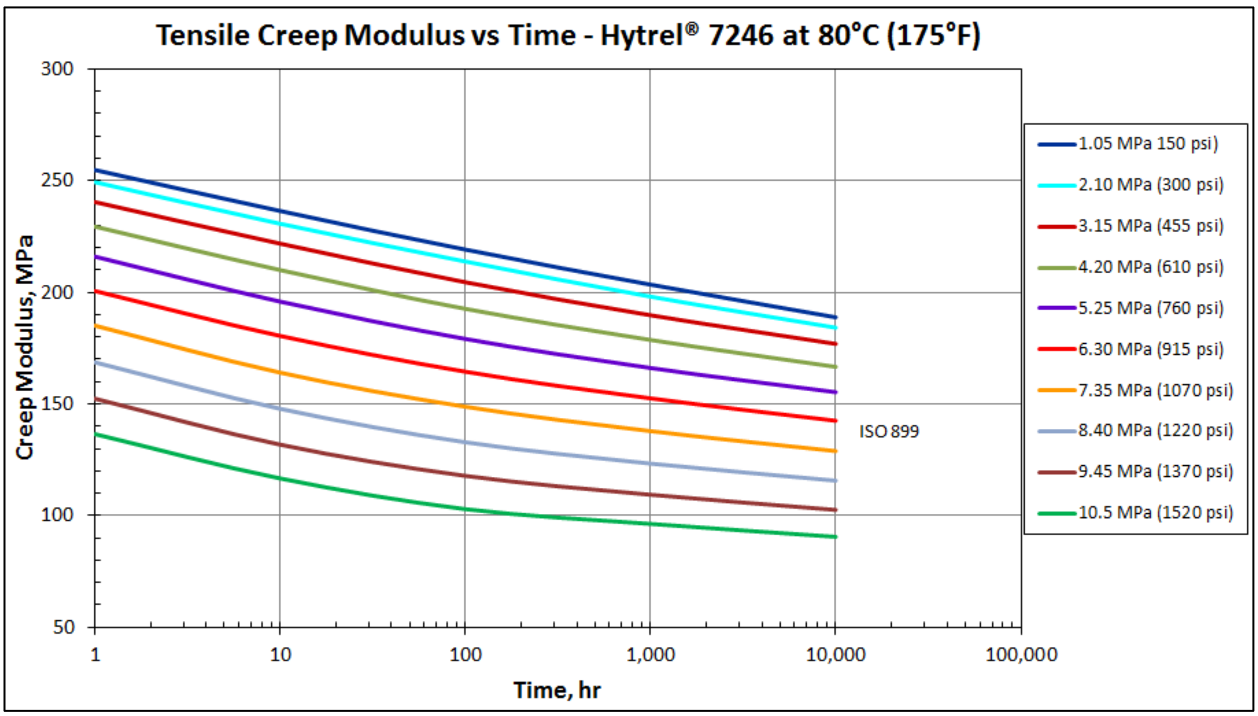


Figure 2.61 Isochronous Stress/Strain Curves – Hytrel® 4056, 23°C (73°F)

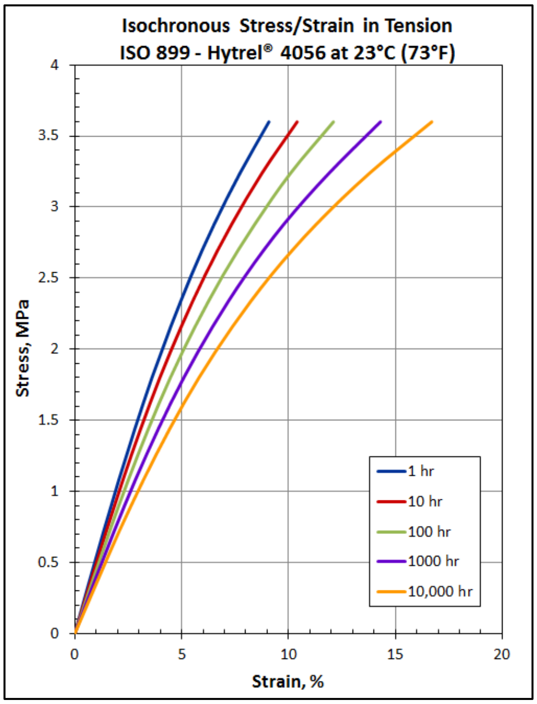


Figure 2.62 Isochronous Stress/Strain Curves – Hytrel® 5556, 23°C (73°F)

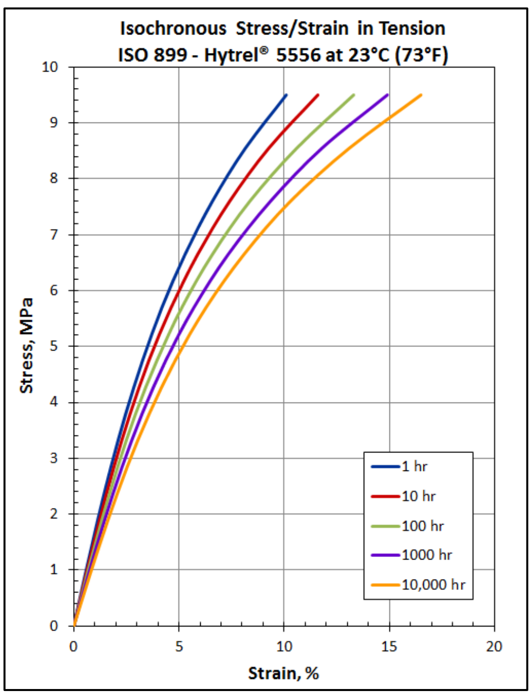


Figure 2.63 Isochronous Stress/Strain Curves – Hytrel® 6356, 23°C (73°F)

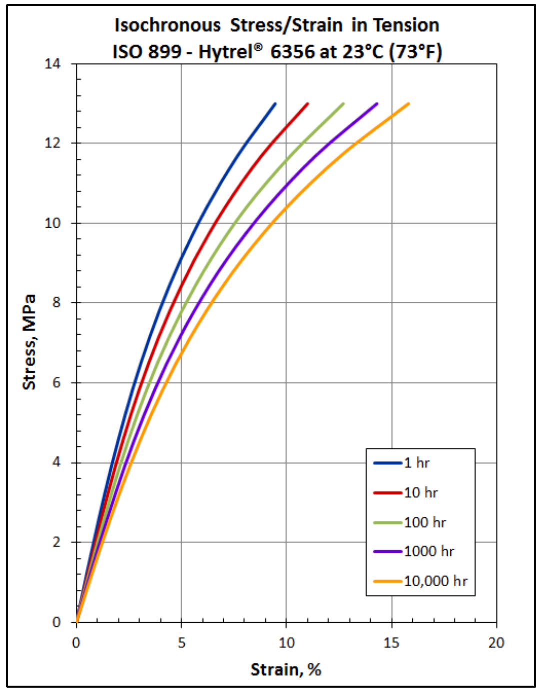


Figure 2.64 Isochronous Stress/Strain Curves – Hytrel® 7246, 23°C (73°F)

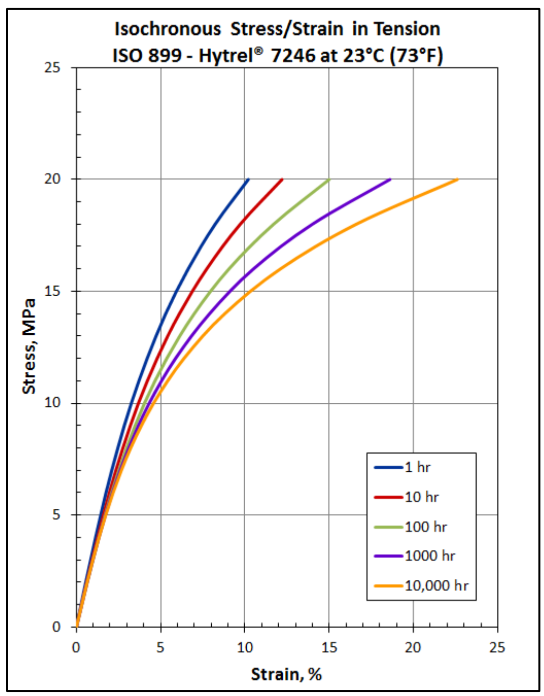


Figure 2.65 Isochronous Stress/Strain Curves – Hytrel® 4056, 40°C (105°F)

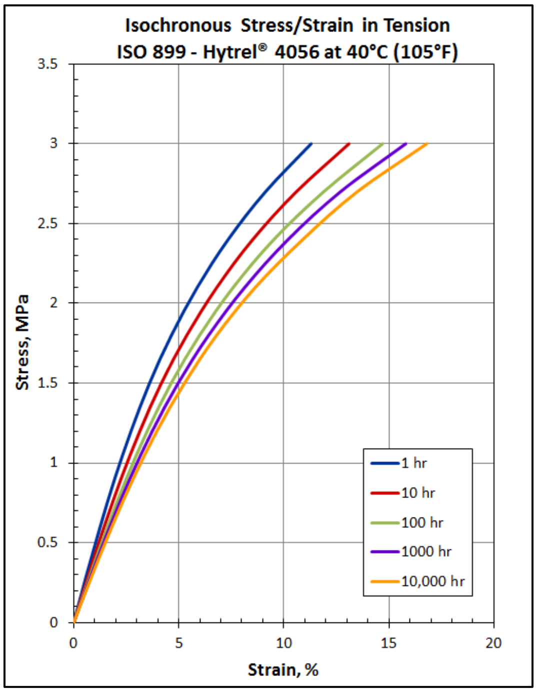


Figure 2.66 Isochronous Stress/Strain Curves – Hytrel® 5556, 40°C (105°F)

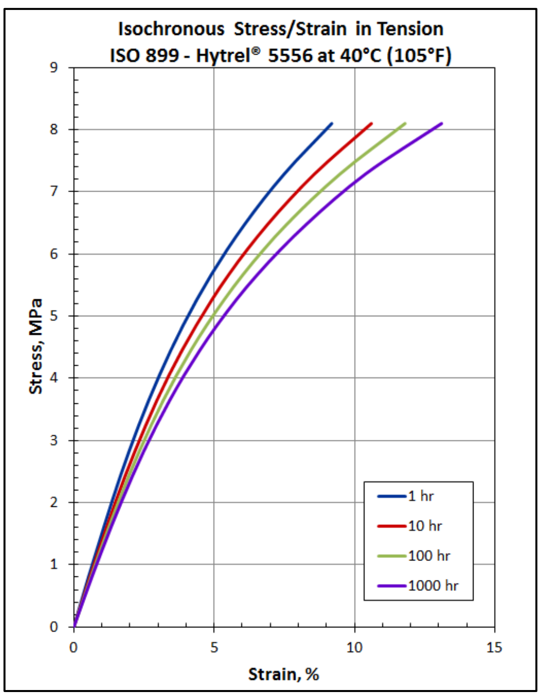


Figure 2.67 Isochronous Stress/Strain Curves – Hytrel® 6356, 40°C (105°F)

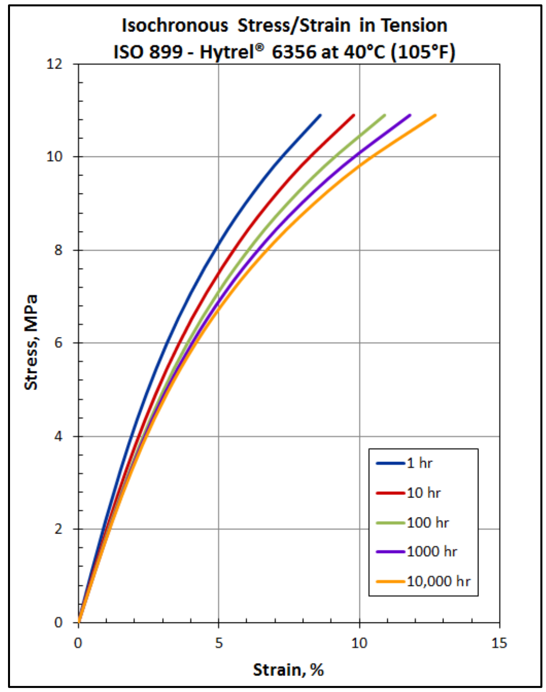


Figure 2.68 Isochronous Stress/Strain Curves – Hytrel® 7246, 40°C (105°F)

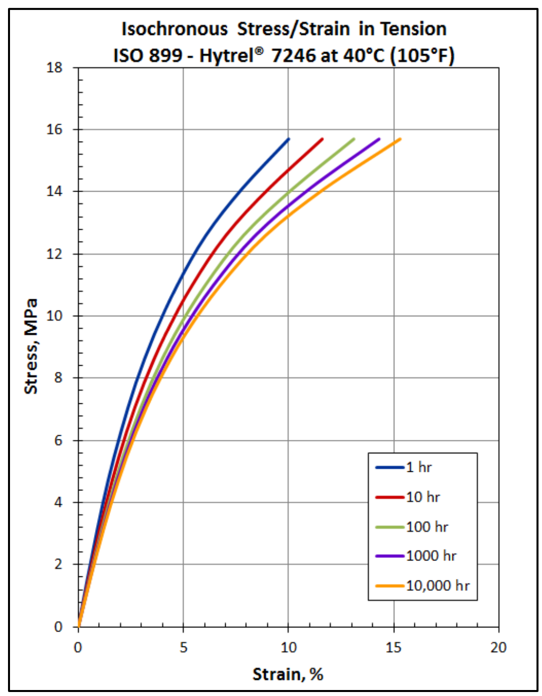


Figure 2.69 Isochronous Stress/Strain Curves – Hytrel® 4056, 80°C (175°F)

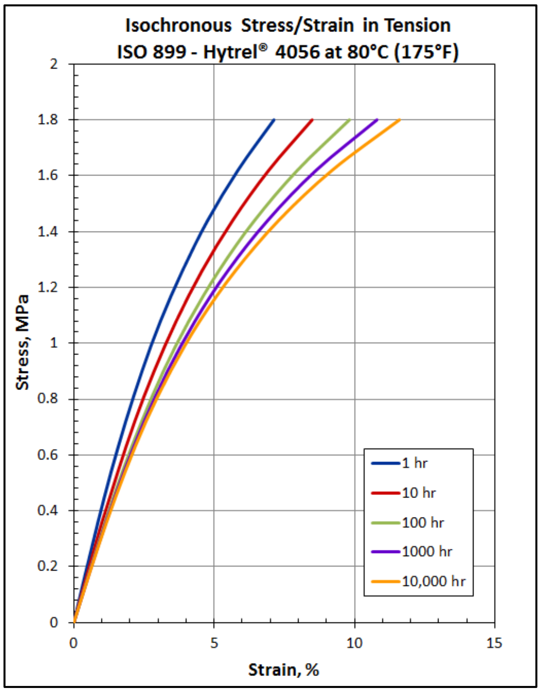


Figure 2.70 Isochronous Stress/Strain Curves – Hytrel® 5556, 80°C (175°F)

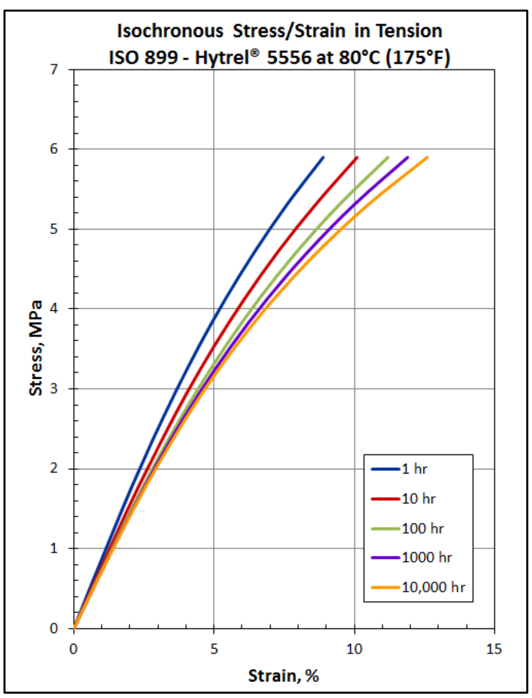


Figure 2.71 Isochronous Stress/Strain Curves – Hytrel® 6356, 80°C (175°F)

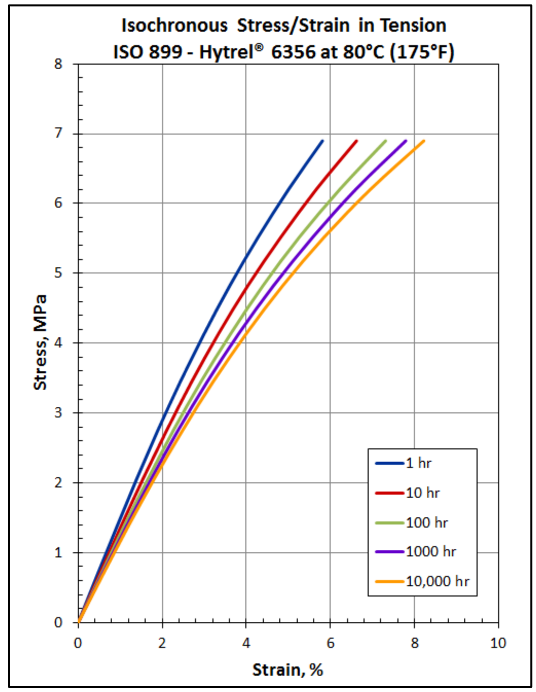
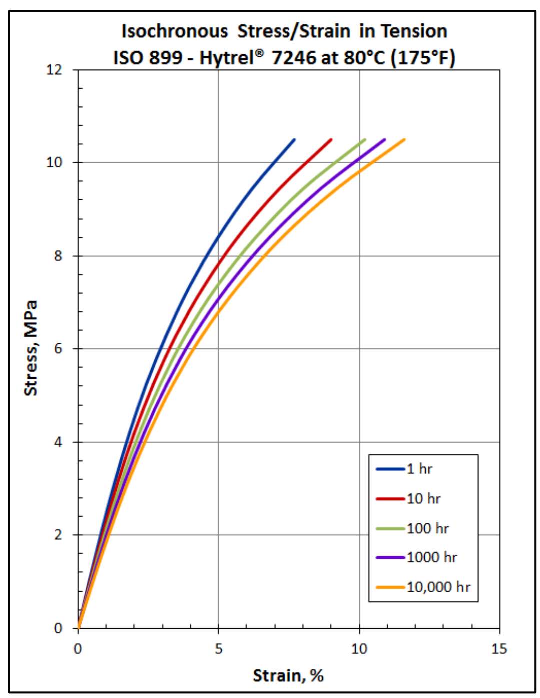


Figure 2.72 Isochronous Stress/Strain Curves – Hytrel® 7246, 80°C (175°F)



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 2.2**. 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 (obtained using the tensile creep isochronous stress/strain curves) shown in the same table.

Table 2.2 Creep Strain – 100 hr at 6.9 MPa (1000 psi) Stress

	Compressive Creep - Strain, %		Tensile Creep - Strain, %
Hytrel® Grade	23°C (73°F)	50°C (122°F)	23°C (73°F)
4056	5.4	8.9	-
G4074	6.0	11.5	-
5526/5556	0.6	1.3	7.0
6356	0.5	0.7	5.0
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

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 2.3 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 2.3 Flex Fatigue, ASTM D 671

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

* Samples tested to 2.5 x 10^6 cycles without failure

Heat Generation and Flexural Fatigue in Compression

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 2.4 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 2.4 – Goodrich Flexometer, ASTM D 623 2.54 mm (0.1 in) Stroke, 1.0 MPa (145 psi) Static Load, 23°C (73°F)

Hytrel® Grade	Sample Temperature After 20 min
4056	48°C (118°F)
5556	66°C (151°F)

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

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 2.5** as the number of cycles it took the specimen to grow five times the original pierced length.

Table 2.5 Resistance to Flex Cut Growth, Ross (Pierced), ASTM D1052

Hytrel® Grade	Cycles to Five Times Cut Growth
G3548(1)	>1x10^6
G4074, G4078LS(1)	>1x10^6
G4774	>1x10^6
G5544	8x10^5
3078	>1x10^6
4056	>1x10^6
4069	>1x10^6
4556	>1x10^6
5526, 5556	5x10^5
6356	5x10^5
7246	3x10^4
HTR4275 BK316	5x10^4
5555HS	1x10^5
HTR5612BK	6x10^5

(1) Data generated on a similar grade

DeMattia Flex

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 2.6** as the number of cycles it took for the specimen to reach failure.

Table 2.6 DeMattia Flex Life (Pierced), ASTM D 813, Cycles to Failure

Hytrel® Grade	Cycles to Failure, 23°C (73°F)
G3548(1)	3.6x10^4
G4074, G4078LS(1)	3.6x10^4
G4774	1.6x10^5
G5544	7x10^3
4056	>1x10^6
4068, 4069	1.7x10^5
4556	3.6x10^3
5526, 5556	>1x10^6
HTR4275 BK316	5.4x10^4
HTR5612BK	1.1x10^5

(1) Data generated on a similar grade

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 materials can still have good impact strength; while at high rates of impact, even highly elastomeric materials 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 Charpy Impact

The objective of the impact test is to measure the behavior of a standard notched test specimen to a pendulum-type impact load. The test specimen, supported as a horizontal beam, is broken by a single swing of the pendulum, with the line of impact directly opposite the single notch. 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 1.2**, at room temperature and at -30 and/or -40°C.

Instrumented Impact

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 2.73- 2.77** 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 2.73 Drop Weight Impact Failure Energy versus Temperature – Hytrel®

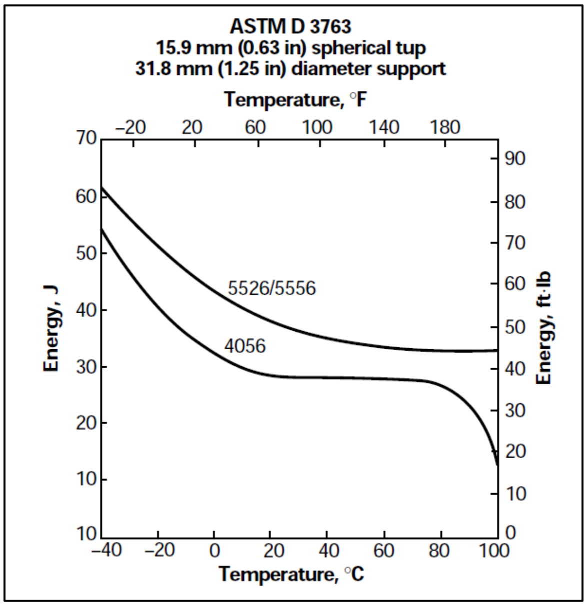


Figure 2.74 Drop Weight Impact Failure Energy versus Temperature – Hytrel®

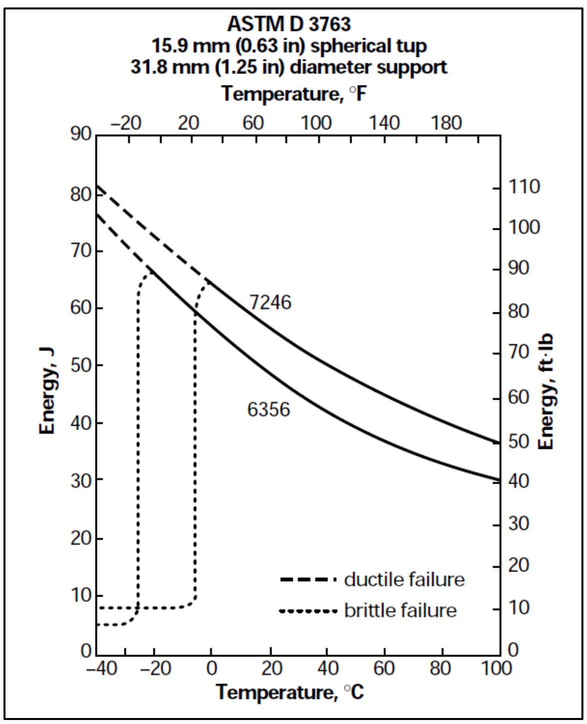


Figure 2.75 Drop Weight Impact Failure Load versus Temperature – Hytrel®

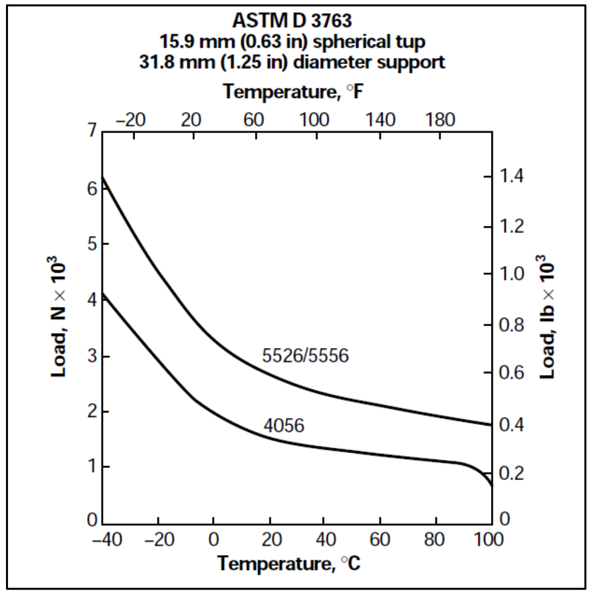


Figure 2.76 Drop Weight Impact Failure Load versus Temperature – Hytrel®

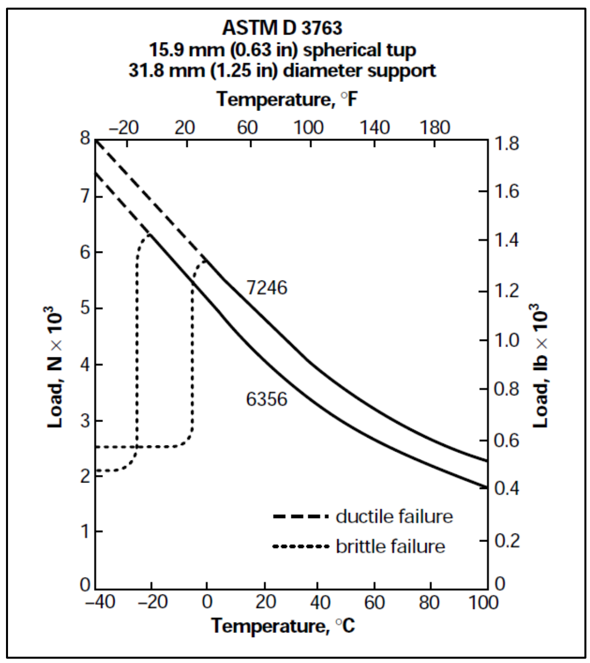
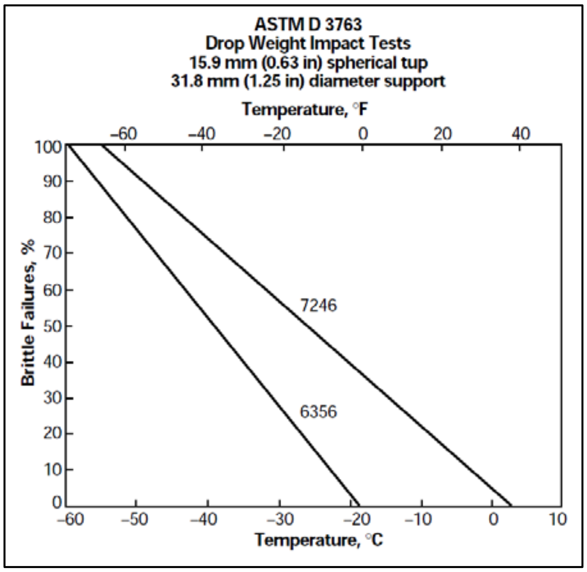


Figure 2.77 Percentage of Brittle Failures versus Temperature – Hytrel®



Brittleness Temperature

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 2.7** lists the brittleness temperatures for representative grades of Hytrel®.

Table 2.7 Brittleness Temperature, ISO 974

	Brittleness Temperature ISO 974	
	°C	°F
Hytrel® 3078	<-90	<-130
Hytrel® 4056	-90	-130
Hytrel® 4069	<-90	<-130
Hytrel® 4556	<-90	<-130
Hytrel® 5526	<-90	<-130
Hytrel® 5555HS	-80	-112
Hytrel® 5556	<-90	<-130
Hytrel® 6356	<-90	<-130
Hytrel® 7246	<-90	<-130
Hytrel® 8238	-84	-120
Hytrel® G3548	-60	-76
Hytrel® G4074	-60	-76
Hytrel® G4078LS(1)	-60	-76
Hytrel® G4774	-66	-87
Hytrel® G4778	-64	-83
Hytrel® G5544	-61	-78
Hytrel® DYM250S BK472	<-90	<-130
Hytrel® DYM350BK	<-90	<-130
Hytrel® HTR237BG BK320	<-90	<-130
Hytrel® HTR4275 BK316	<-90	<-130
Hytrel® HTR6108	<-70	<-94
Hytrel® HTR8068	-48	-54
Hytrel® HTR8139BK	<-90	<-130
Hytrel® HTR8163HVBK	<-70	<-70
Hytrel® HTR8223 BK320	<-90	<-130

(1) Data based on similar grade

Section 3 - Thermal Properties

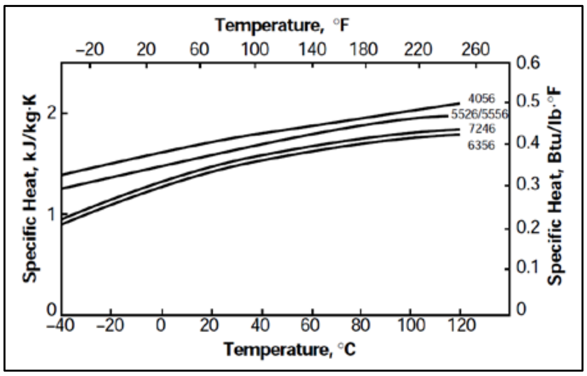
Thermal Conductivity and Specific Heat

Thermal conductivity data are shown in **Table 3.1**, and **Figure 3.1** is a plot of specific heat versus temperature for several grades of Hytrel®.

Table 3.1 Thermal Conductivity, test specimens 51 x 6.4 mm (2 x 0.25 inch) disks

	Thermal Conductivity, W/m°K (Btu/hr ft °F) ASTM C518	
	50°C (122°F)	100°C (212°F)
Hytrel® G3548	0.18 (0.10)	0.18 (0.10)
Hytrel® G4078, G4078LS	0.19 (0.11)	0.19 (0.11)
Hytrel® 3078	0.19 (0.11)	0.19 (0.11)
Hytrel® 4069	0.20 (0.12)	0.19 (0.11)
Hytrel® 4556	0.21 (0.12)	0.20 (0.12)
Hytrel® 5556	0.21 (0.12)	0.21 (0.12)
Hytrel® 6356	0.21 (0.12)	0.21 (0.12)
Hytrel® 7246	0.22 (0.13)	0.22 (0.13)

Figure 3.1 Specific Heat versus Temperature



Coefficient of Linear Thermal Expansion

Coefficients of linear thermal expansion measured by Thermal Mechanical Analysis (TMA) for Hytrel® are presented in **Table 3.2**.

Table 3.2 Coefficient of Linear Thermal Expansion

		CLTE, E-4/°C (E-4/°F), ISO 11359-1/-2		
		-40 - 23°C (-40 - 73°F)	23 - 55°C (73 - 130°F)	55 - 120°C (130 - 250°F)
Hytrel® 3078	Parallel	2.1 (1.17)	1.77 (0.98)	
	Normal	3.2 (1.78)	2.06 (1.15)	
Hytrel® 4056	Parallel	2.0 (1.11)	1.3 (0.72)	
	Normal	1.8 (1.0)	1.6 (0.89)	
Hytrel® 4069	Parallel	2.6 (1.4)	2.2 (1.2)	1.2 (0.67)
	Normal	2.7 (1.5)	1.9 (1.1)	1.9 (1.1)
Hytrel® 4556	Parallel	2.2 (1.22)	1.71 (0.95)	1.9 (1.06)
	Normal	2.1 (1.17)	1.87 (1.04)	1.9 (1.06)
Hytrel® 5556	Parallel	1.6 (0.89)	1.8 (1.0)	1.86 (1.03)
	Normal	1.74 (0.97)	1.77 (0.98)	1.79 (0.99)
Hytrel® 6356	Parallel	1.54 (0.86)	1.78 (0.99)	1.81 (1.01)
	Normal	1.48 (0.82)	1.76 (0.98)	1.79 (0.99)
Hytrel® 7246	Parallel	1.2 (0.67)	1.8 (1.0)	1.8 (1.0)
	Normal	1.3 (0.72)	1.7 (0.94)	1.8 (1.0)
Hytrel® 8238	Parallel	1.03 (0.57)	1.47 (0.82)	1.69 (0.94)
	Normal	0.09 (0.05)	1.49 (0.83)	1.46 (0.81)
Hytrel® G3548	Parallel	2.2 (1.22)	2.1 (1.17)	0.82 (0.45)
	Normal	2.0 (1.11)	2.1 (1.17)	2.6 (1.4)
Hytrel® G4074	Parallel	1.91 (1.06)	2.17 (1.2)	1.74 (0.97)
	Normal	2.27 (1.26)	2.05 (1.14)	2.12 (1.18)
Hytrel® G4078	Parallel	2.0 (1.11)	2.1 (1.17)	2.2 (1.22)
	Normal	1.8 (1.0)	1.9 (1.06)	1.7 (0.94)
Hytrel® G4078LS	Parallel	2.1 (1.17)	2.1 (1.17)	1.8 (1.0)
	Normal	1.8 (1.0)	1.9 (1.06)	1.8 (1.0)
Hytrel® G4774	Parallel	2.1 (1.17)	2.2 (1.22)	1.9 (1.06)
	Normal	1.9 (1.06)	1.94 (1.08)	1.9 (1.06)
Hytrel® G5544	Parallel	1.9 (1.06)	2.11 (1.17)	2.0 (1.11)
	Normal	1.7 (0.94)	1.86 (1.03)	1.7 (0.94)

Dynamic Properties

These measurements are made by Dynamic Mechanical Analysis (DMA) technique. The measurements are made at varying temperatures. The dynamic modulus represented in **Figure 3.2** represents the load-bearing capability or stiffness of the plastic materials, while the maximum of the tan delta curve or the damping factor represented in **Figure 3.3** 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 application such as motor mounts and couplings.

Figure 3.2 Dynamic Modulus versus Temperature (at 1 Hz frequency)

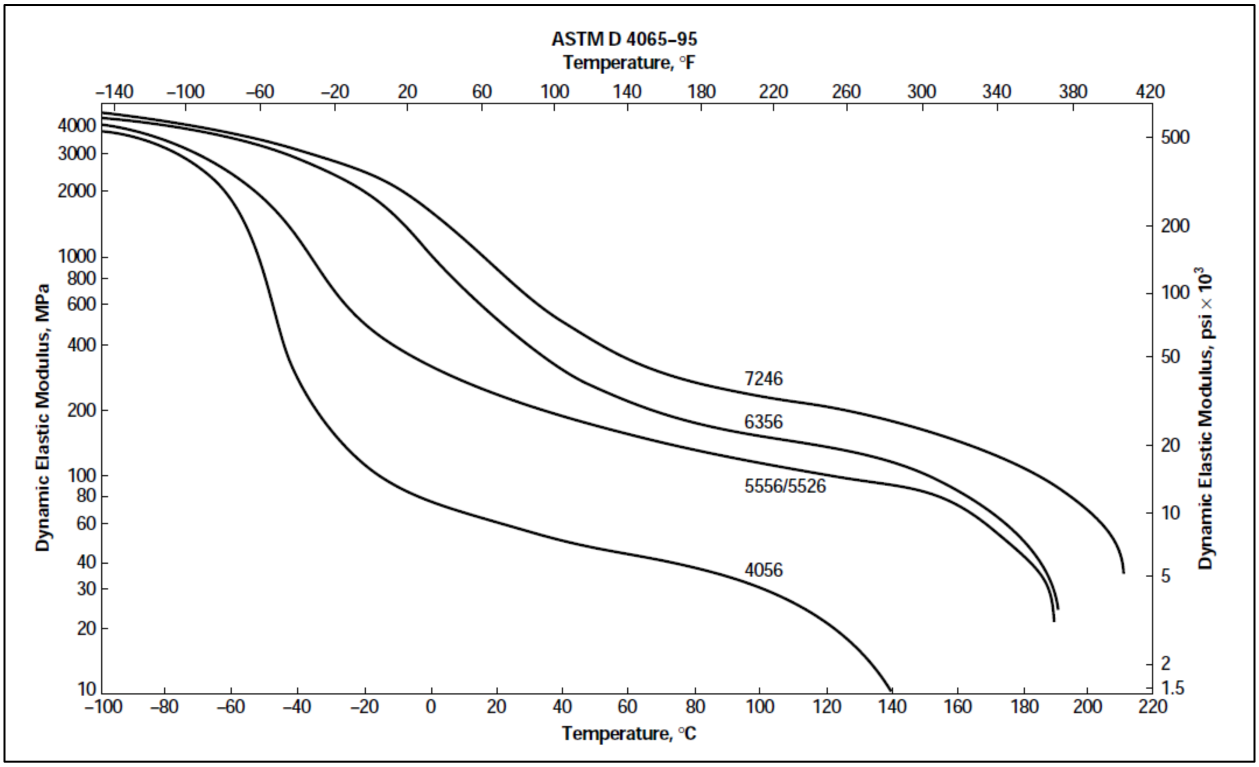
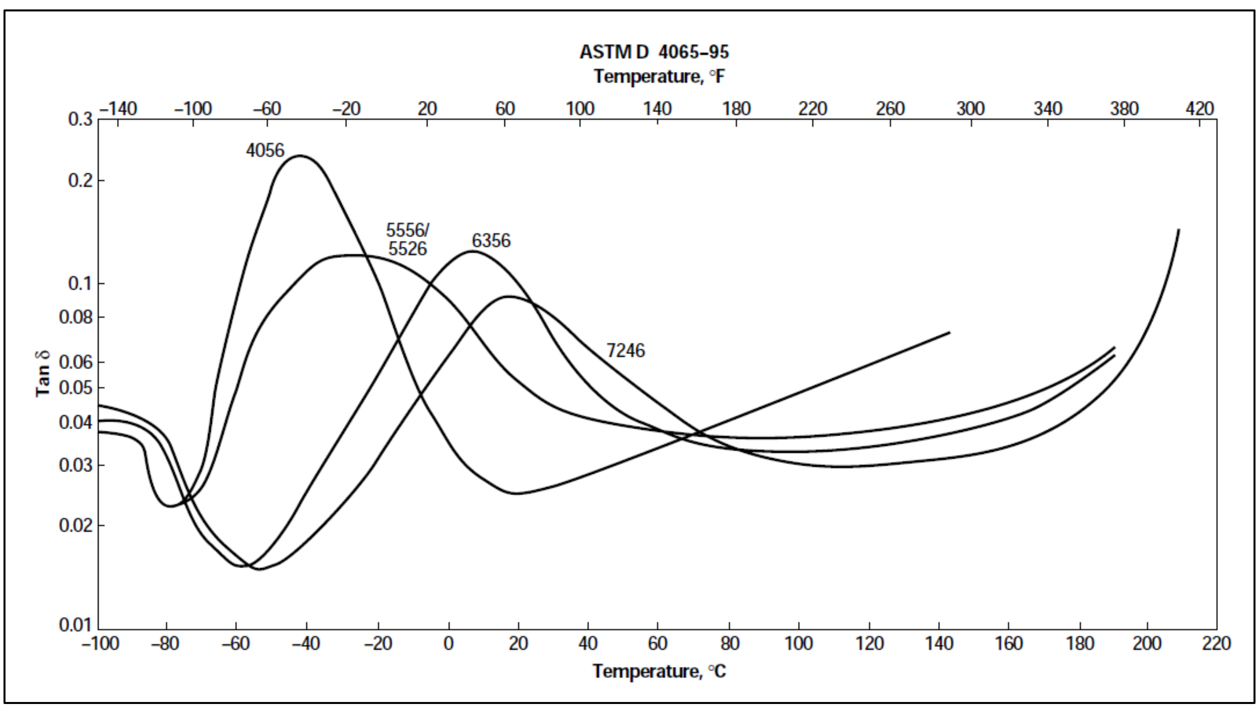


Figure 3.3 Damping Factor versus Temperature (at 1 Hz frequency)



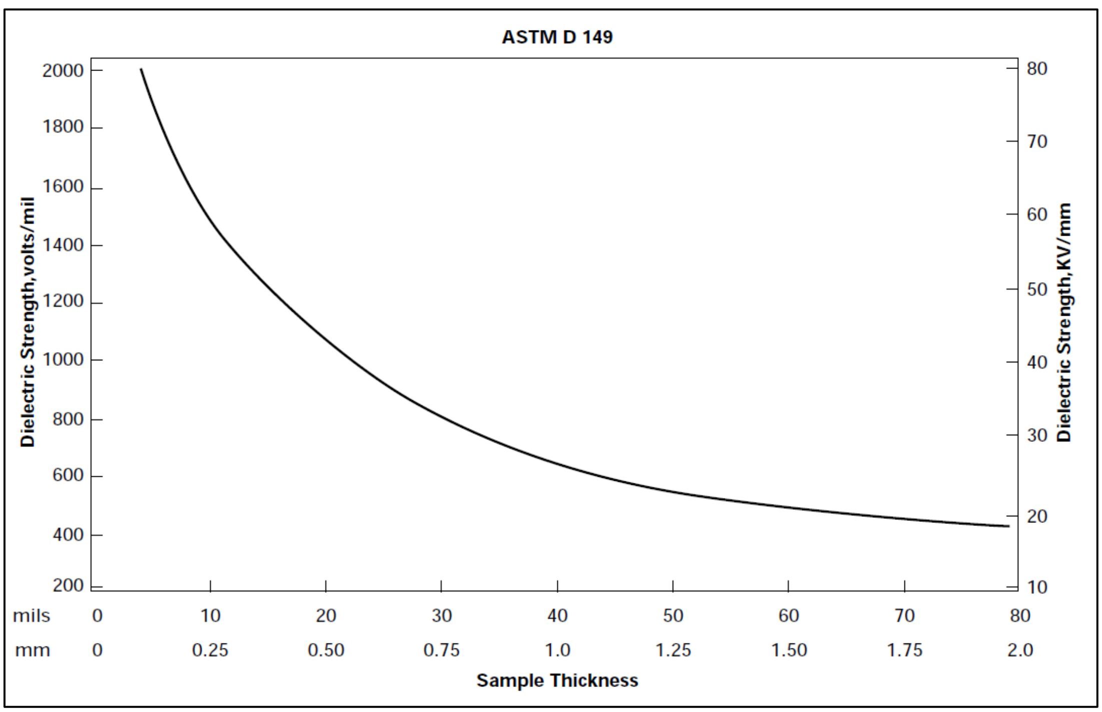
Section 4 - Electrical Properties

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® a good option for many jacketing applications. The properties shown in **Table 4.1** were measured according to IEC standards. **Figure 4.1** shows the dependence of dielectric strength on thickness for Hytrel® 5556. A similar relationship applies for the other grades of Hytrel®.

Table 4.1 Electrical Properties at 23°C (73°F)

	Surface Resistivity, ohm	Volume Resistivity, ohm m	Electric Strength, kV/mm IEC 60243-1		Relative Permittivity IEC 60250		Dissipation Factor, E-4 IEC 60250	
	IEC 60093	IEC 60093	1 mm	2 mm	1E2 Hz	1E6 Hz	1E2 Hz	1E6 Hz
Hytrel® 3078	1E+14	1E+11	28	20	5.4	5.3	70	150
Hytrel® 4056	1E+14	1E+11	29	21	5.5	4.8	150	500
Hytrel® 4068, 4069	1E+14	1E+11	29	21	5.1	4.8	150	170
Hytrel® 4556	1E+14	1E+11	29	21	5.1	4.8	150	250
Hytrel® 5526	1E+14	1E+11	29	20	5.1	4.6	100	380
Hytrel® 5555HS	1E+14	1E+11	35	24	5.1	4.5	150	420
Hytrel® 5556	1E+14	1E+11	30	20	5.0	4.5	100	380
Hytrel® 6356	1E+14	1E+12	32	21	4.8	4.2	100	380
Hytrel® 7246	1E+14	1E+13	32	21	4.3	3.8	200	320
Hytrel® 8238	1E+14	1E+14	32	22	4.0	3.5	100	240
Hytrel® G3548	1E+13	1E+09	20	17	7.0	5.9		450
Hytrel® G4074	1E+13	1E+09	22	20	6.5	5.2		530
Hytrel® G4078	1E+13	1E+10	22	20	6.5	5.2		530
Hytrel® G4078LS	1E+13	1E+10	28	20	6.0	5.0	500	530
Hytrel® G4774		1E+12	28	20	4.5	4.8	550	
Hytrel® G5544	1E+14	1E+10	30	20	4.5	4.0	150	300
Hytrel® HTR8068	1E+12	1E+09	28	20	6.5	5.0		530
Hytrel® HTR6108			30	20	4.7	4.0	320	420

Figure 4.1 Dielectric Strength versus Thickness – Hytrel® 5556



Section 5 - Abrasion and Wear

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* is 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 5.1**. 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.

Table 5.1 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

Wear

Measurement of wear may be determined by volume loss, weight loss, or thickness loss on the test specimen under the force of abrasive wheel or drum held under specified load against the test specimen.

Hytrel® engineering thermoplastic elastomer has excellent wear properties in many applications. **Table 5.2** lists results from abrasion resistance tests.

Table 5.2 Abrasion Resistance According to ISO 4649 and ASTM D 1044

	Abrasion Resistance, mm³	Taber Abrasion, mg/1000 rev ASTM D1044	
Type of Hytrel®	ISO 4649 Method A	CS-17 Wheel	H-18 Wheel
High Performance			
3078	-	2	90
4056	200	3	100
4069	-	15	80
4556	130	3	72
5526	120	7	70
5556	120	6	64
6356	110	7	77
7246	100	-	-
8238	-	9	20
General Purpose			
G3548(1)	-	30	310
G4074, G4078(1)	50	20	260
G4774	33	13	168
G5544	-	9	116
Specialty			
HTR4275 BK316	-	20	227
5555HS	-	-	112
HTR8068	-	25	-

(1) Data generated on a similar grade

Section 6 - Effect of Environment

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.

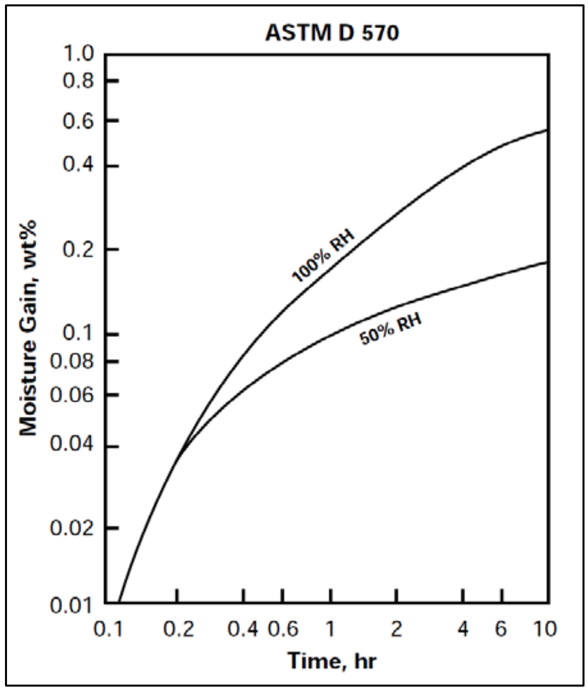
At temperatures above the melting point, excessive moisture causes hydrolytic degradation of the polymer. Such degradation results in poor physical properties and brittleness, particularly at low temperatures.

Equilibrium moisture levels depend on the grade as reported in **Table 6.1**. The rate of moisture absorption for Hytrel® 5556 is shown in **Figure 6.1.**

Table 6.1 Moisture Absorption of Hytrel®

	Water Absorption, % - ISO 62		
	Equilibrium 50%RH	Immersion 24h	Saturation, immersed
Hytrel® 3078	0.2	0.5	0.8
Hytrel® 4056	0.2	0.6	0.7
Hytrel® 4068, 4069	0.3	0.7	0.7
Hytrel® 4556	0.2	0.6	0.6
Hytrel® 5526	0.2	0.6	0.6
Hytrel® 5555HS	0.2	0.7	0.6
Hytrel® 5556	0.2	0.6	0.6
Hytrel® 6356	0.2	0.5	0.6
Hytrel® 7246	0.2	0.3	0.6
Hytrel® 8238	0.2	0.3	0.6
Hytrel® G3548 NC010	0.8	6.9	12
Hytrel® G4078 NC010	0.7	3.4	6.5
Hytrel® G4078LS NC010	0.7	3.5	6.8
Hytrel® G4774	-	2.5	-
Hytrel® G5544	0.4	1.6	2.2
Hytrel® DYM350BK	0.2	0.6	0.6
Hytrel® HTR4275 BK316	0.2	0.5	0.5
Hytrel® HTR8068	-	1.9	-
Hytrel® HTR8139BK	0.2	0.7	0.7
Hytrel® HTR8206	1.3	30	35
Hytrel® HTR8223 BK320	0.2	0.6	0.8
Hytrel® HTR8303	-	0.4	-
Hytrel® HTR8341C BK320	0.2	-	0.5

Figure 6.1 Moisture Absorption at Ambient Temperature – Hytrel® 5556

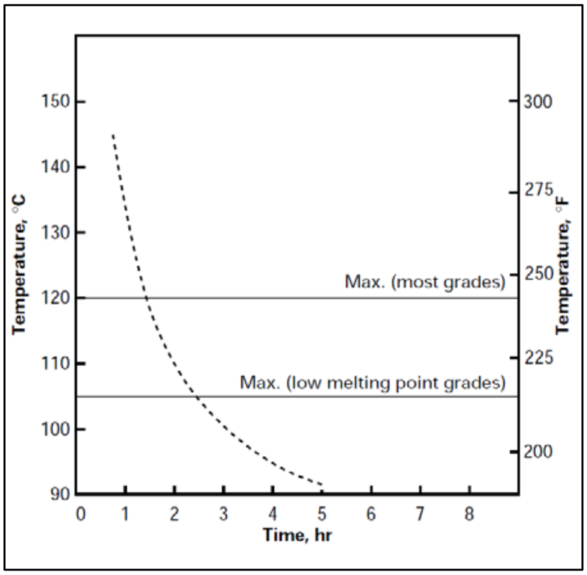


Hytrel® thermoplastic elastomer must be dried prior to processing, which is critical to making quality parts that will give good service performance.

Also, in the case of critical extrusion operations, such as vacuum calibration of tubes to tight 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 6.2.**

Figure 6.2 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 molded at standard conditions:

• Mold temperature: 45°C (115°F)

• Injection pressure: 70 MPa (10,150 psi)

• SFT: optimum

Table 6.2 gives the nominal shrinkage values for various grades of Hytrel®, obtained under these standard conditions.

Table 6.2 Molding Shrinkage of Hytrel®

	Molding Shrinkage, %, 2.0 mm thickness	
	ISO 294-4	
	Parallel	Normal
Hytrel® 3078	0.6	0.6
Hytrel® 4056	0.2	0.4
Hytrel® 4068, 4069	0.8	0.8
Hytrel® 4556	1.1	1.1
Hytrel® 5526, 5556	1.4	1.4
Hytrel® 5555HS	1.5	1.5
Hytrel® 6356	1.5	1.5
Hytrel® 7246	1.6	1.6
Hytrel® 8238	1.6	1.6
Hytrel® G3548 NC010	0.8	0.8
Hytrel® G4074	0.8	0.8
Hytrel® G4078, G4078LS	0.5	1.1
Hytrel® G4774	1.5	1.2
Hytrel® G5544	1.6	1.6
Hytrel® DYM250S BK472	1.2	1.2
Hytrel® DYM350BK	1.3	1.4
Hytrel® HTR4275 BK316	1.7	1.9
Hytrel® HTR6108	0.3	0.7
Hytrel® HTR8068	1.1	1.1
Hytrel® HTR8139BK	1.6	1.4
Hytrel® HTR8206	1.4	1.5
Hytrel® HTR8223 BK320	1.6	1.6
Hytrel® HTR8303	2.6	2.5
Hytrel® HTR8441 BK316	2.2	2.1
Hytrel® HTR8685 BK022A	1.7	1.6

Figures 6.3 – 6.5 show the influence of different injection molding parameters on shrinkage. 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 6.2** in order to get a first approximation of the final shrinkage. The shrinkage evaluation for precision parts should be made using a prototype tool.

Figure 6.3 Influence of Mold Temperature on Shrinkage

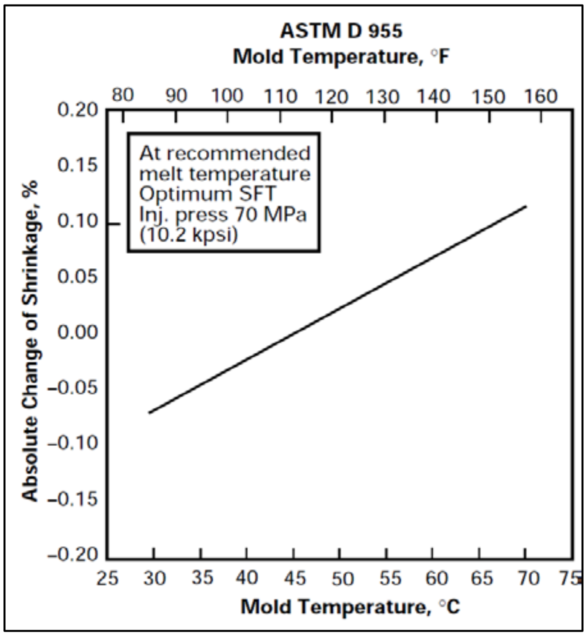


Figure 6.5 Influence of Injection Pressure on Shrinkage

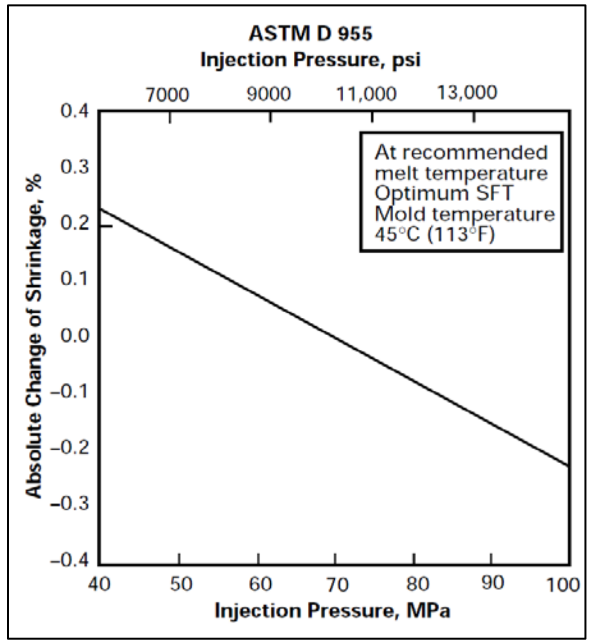
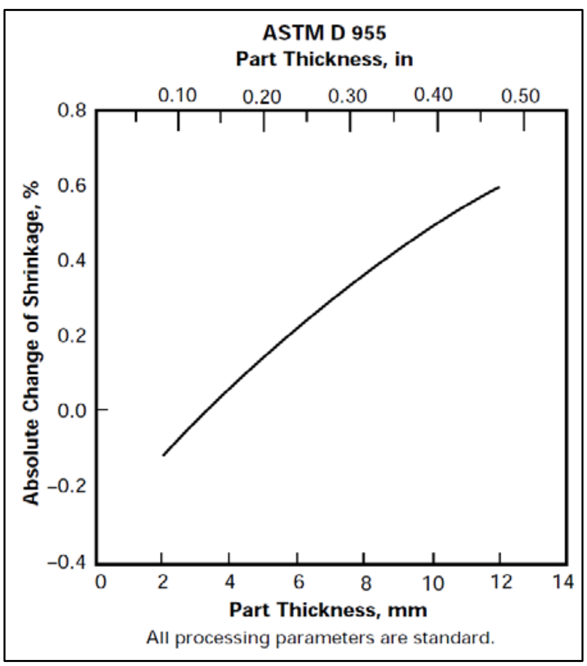


Figure 6.4 Influence of Part Thickness on Shrinkage



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

Nominal shrinkage of Hytrel® 5526 (Table 6-2):	1.40%
Use of 65°C mold temperature versus 45°C (Figure 6-3):	+0.09%
Use of injection pressure of 900 bar versus 700 bar (Figure 6-5):	–0.15%
Total shrinkage is approximately:	1.34%

Annealing

Post-molding shrinkage is measured after annealing parts at 120°C (250°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

DuPont offers various additive-containing concentrates, such as Hytrel® 21UV, Hytrel® 30HS, Hytrel® 40CB, Hytrel® 52FR and Hytrel® 60LW.

Each concentrate is designed to be blended with other Hytrel® resins to enhance specific properties.

Table 6.3 Hytrel® Concentrates

Grade	Description	Characteristics and Typical Uses
Hytrel® 21UV	UV light stabilizer concentrate.	Used for protection of light-colored parts and/or black thin 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 letdown ratio for direct outdoor exposure is 7:1.
Hytrel® 52FR	Flame retardant concentrate	52FR is a concentrate containing 67% by weight of a brominated flame retardant and antimony oxide synergist dispersed in Hytrel® 5556. A letdown ratio of 10:1 will yield oxygen indices of 21–30 (ASTM D2863) and a UL rating of V-2.
Hytrel® 60LW	Lubricant concentrate	60LW is a concentrate intended to improve wear and friction properties of Hytrel® grades. The carrier is a 63D hardness Hytrel® grade and processing should always be carried out at melt temperatures that ensure it is fully melted, preferably 240°C (465°F) or above.

* 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.

UV Exposure/Weathering

Over a period of time, exposure to ultraviolet light adversely affects the appearance and properties of many plastics. The addition of Hytrel® 40CB concentrate (for black parts) or Hytrel® 21UV concentrate (for parts that are natural color or colors other than black) to all Hytrel® products used outdoors or exposed to direct sunlight via windows or reflective surfaces will result in improved UV resistance.

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

Hytrel® 21UV blended with Hytrel® may discolor with time. Where color is important, the use of pigments in combination with Hytrel® 21UV is recommended.

The use of Hytrel® 40CB and 21UV concentrates together blended with Hytrel® can provide additional UV resistance for critical applications.

Table 6.4 Xenon Arc Weatherometer Exposure, per ASTM G155, Cycle 8 (SAE J1885)*

	UV Exposure, kJ/m2	Hytrel® 4056	Hytrel® 4056 & 40CB (16:1)	Hytrel® 4056 & 40CB (7:1)	Hytrel® 4056 & 21UV* (40:1)	Hytrel® 4056 & 21UV* (25:1)	Hytrel® 5556	Hytrel® 5556 & 40CB (16:1)	Hytrel® 5556 & 40CB (7:1)	Hytrel® 5556 & 21UV* (40:1)	Hytrel® 5556 & 21UV* (25:1)	Hytrel® 8238	Hytrel® 8238 & 40CB (16:1)	Hytrel® 8238 & 40CB (7:1)	Hytrel® 8238 & 21UV* (40:1)	Hytrel® 8238 & 21UV* (25:1)
Tensile Strength, MPa	0	33	28	28	33	29	39	33	35	30	29	48	39	40	41	36
	250	11	25	26	29	26	19	30	30	28	26	36	38	39	36	37
	500	brittle	21	25	28	25	6	28	30	27	25	34	35	35	36	37
	1000	brittle	22	24	26	23	brittle	29	29	26	25	brittle	35	34	37	37
	1500	brittle	20	22	22	20	brittle	28	28	25	23	brittle	35	35	35	35
	2000	brittle	21	23	19	18	brittle	28	29	23	18	brittle	35	35	36	31
Elongation, %	0	562	682	612	794	735	540	559	597	557	571	350	510	563	377	340
	250	591	646	667	774	668	456	555	544	542	586	85	350	349	368	368
	500	brittle	564	676	801	679	30	540	558	561	608	17	350	336	308	442
	1000	brittle	620	675	802	691	brittle	539	540	557	595	brittle	305	305	452	429
	1500	brittle	626	691	837	717	brittle	550	548	562	584	brittle	158	101	458	474
	2000	brittle	662	699	818	716	brittle	551	551	529	493	brittle	261	304	300	453
Gloss, %	0	90	87	87	75	86	92	89	89	88	79	97	93	93	97	96
	250	5	84	82	89	90	17	90	90	92	89	7	87	87	53	87
	500	N/A	96	91	79	81	10	95	97	88	82	20	83	86	15	45
	1000	N/A	66	73	71	67	N/A	89	94	73	74	33	80	76	31	47
	1500	N/A	33	49	10	6	N/A	27	24	25	20	2	27	13	3	6
	2000	N/A	11	29	20	36	N/A	13	9	31	33	36	22	23	36	21
delta E (illum. D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	250	13	3	3	6	6	11	3	3	6	3	16	1	1	3	4
	500	N/A	5	5	7	7	17	6	5	7	5	19	3	3	3	4
	1000	N/A	3	2	19	20	N/A	7	7	13	12	20	4	5	9	8
	1500	N/A	6	4	9	10	N/A	11	12	9	9	21	2	9	4	7
	2000	N/A	5	4	10	11	N/A	5	6	10	10	25	3	4	17	18

* Data generated using a predecessor of 21UV, shown to have similar performance. Test specimens die cut from injection molded 1.9 mm (0.075 inch) thick plaques. Weathering cycle = 3.8 h light, 50% RH, 89°C Black Panel Temperature, 62°C Chamber Air Temperature, 1.0 h dark, 95% RH, 38°C Black Panel Temperature, 38°C Chamber Air Temperature with irradiance of 0.55 W/m2 nm at 340 nm.

Temperature/Time Resistance

Addition of Hytrel® 30HS to Hytrel® products improves aging/thermal stability as shown in **Figures 6.6 through 6.11**.

Hytrel® 5555HS is a specialty grade containing a thermal stabilizer package, so the addition of 30HS is not needed.

Special precautions should be taken to make sure that the 30HS 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 6.6 Heat Aging at 125°C (257°F) – Hytrel® 4069

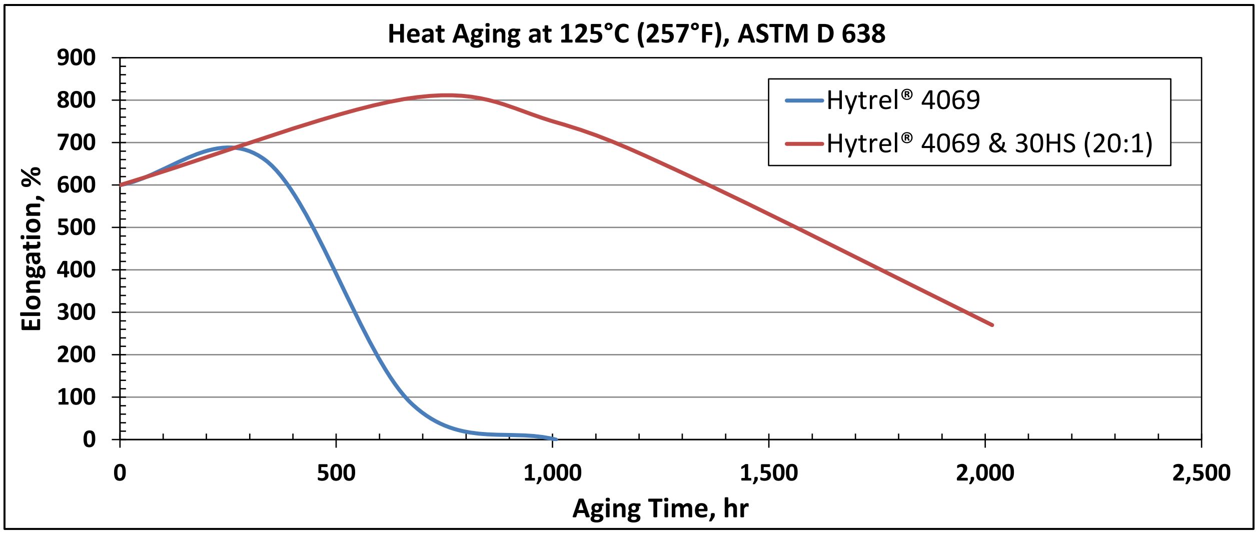


Figure 6.7 Heat Aging – Hytrel® 4069

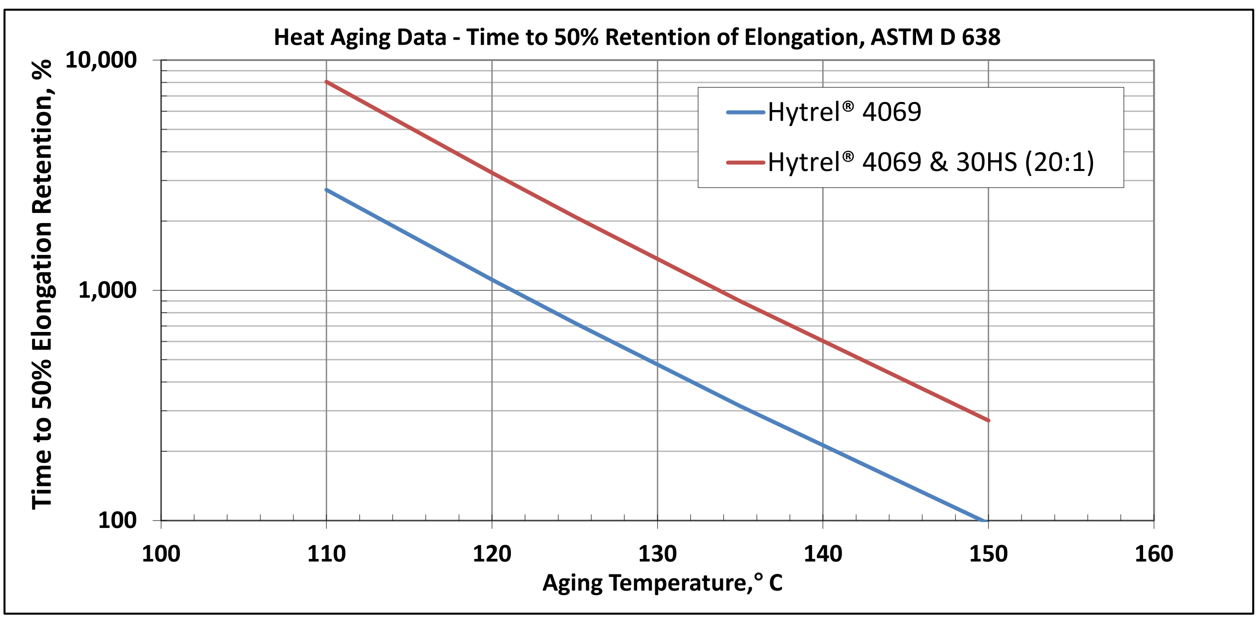


Figure 6.8 135°C (275°F) Heat Aging – Hytrel® 55D Grades

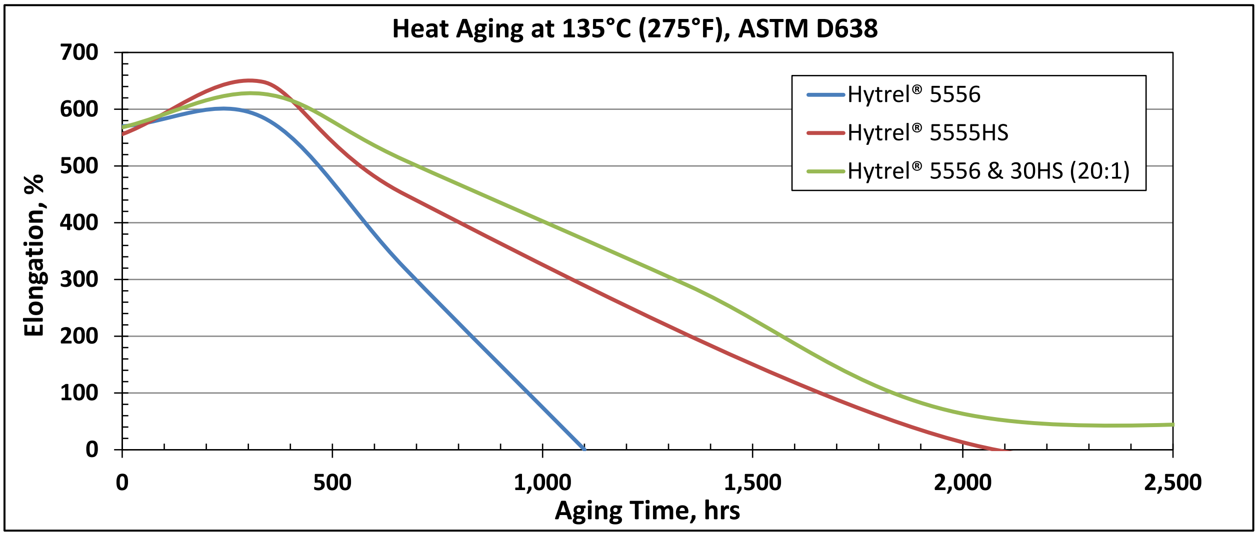


Figure 6.9 Heat Aging – Hytrel® 55D Grades

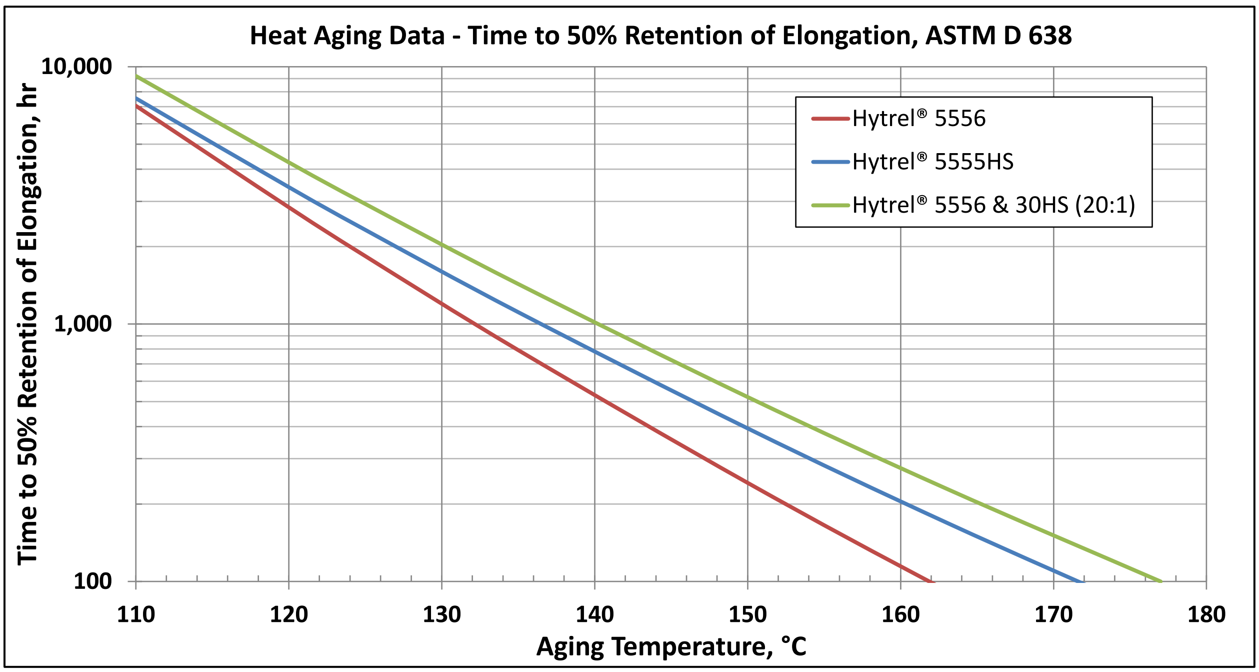


Figure 6.10 Heat Aging at 135°C (275°F) – Hytrel® 7246

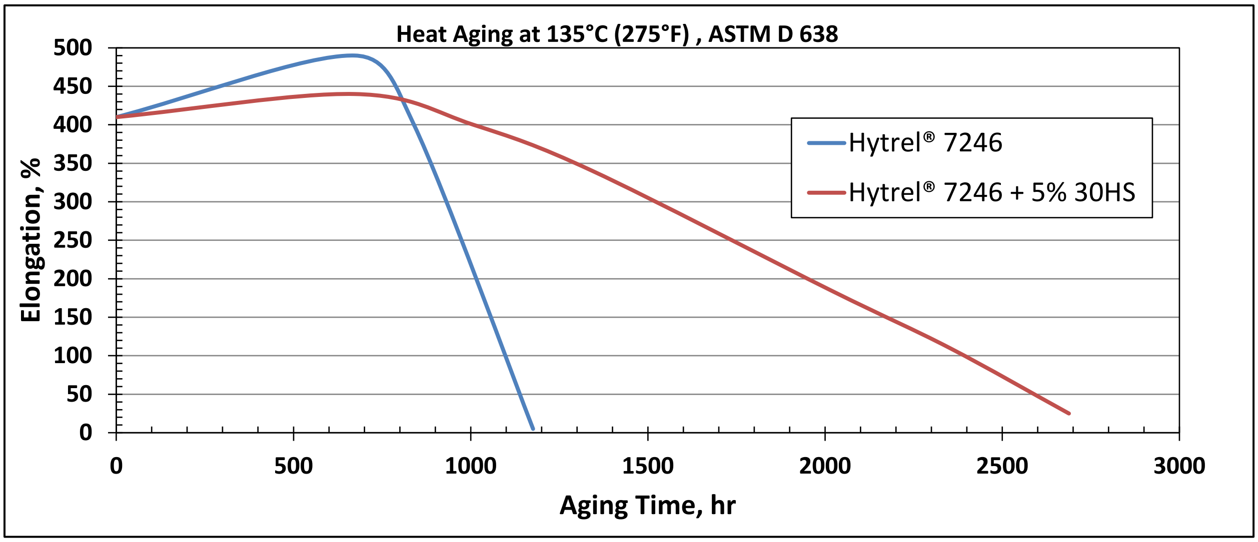
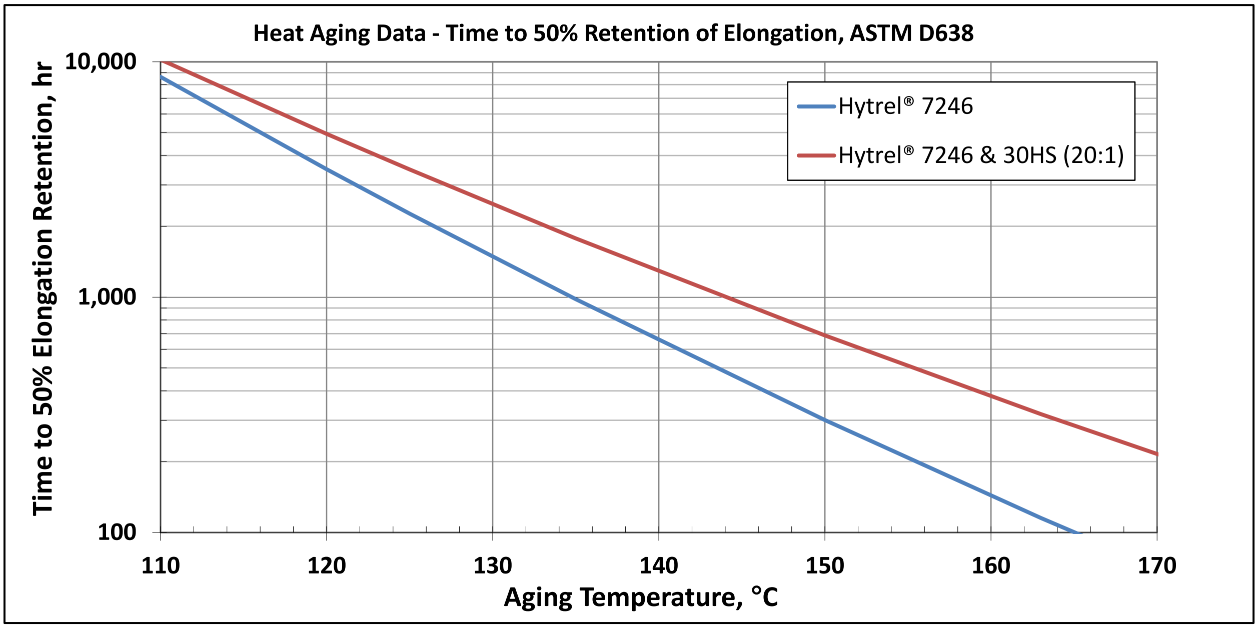


Figure 6.11 Heat Aging – Hytrel® 7246



Flammability

Hytrel® 52FR is a concentrate containing a brominated flame retardant and antimony oxide synergist dispersed in Hytrel® 5556.

Table 6.5 summarizes oxygen index when 52FR is blended into several grades of Hytrel®. Tensile properties are also shown. A letdown ratio of 10:1 (i.e., 10 parts Hytrel® to 1 part flame retardant concentrate) is required to attain an oxygen index of 21–30).

Heat Aging

Incorporation of 52FR in the Hytrel® resins with hardness of 55D or higher gives good retention of tensile properties and melt flow after prolonged aging as shown in **Table 6.6**; however, incorporation of 52FR in Hytrel® resins with hardness less than 55D increased the stiffness and hardness of the blend noticeably.

Incorporation of 52FR in Hytrel® resins shows excellent color stability of the blends after heat aging.

Processing

Trials at melt temperatures up to 230°C (450°F) have shown that 52FR is non-corrosive to nitrided and heat-hardened screws. When operating above this temperature or when employing long equipment residence times, corrosion-resistant equipment (e.g., chrome plating on screws) should be considered.

Additional processing information is contained in bulletin "Rheology and Handling," which is available from your DuPont representative.

Safety During Processing

During processing, several precautions should be taken.

- The Hytrel® flame retardant concentrate may form gaseous decomposition products if processed wet or if overheated or held at processing temperatures longer than 10 minutes.
- If extensive decomposition of 52FR occurs, shut off heat and purge machine with polyethylene.
- Do not mix Hytrel® 52FR with Hytrel® 21UV; blends of these may rapidly decompose, liberating potentially hazardous emissions.

Additional information can be found in the Safety Data Sheet, which can be obtained from your DuPont representative.

Table 6.5 Blends of 52FR in Hytrel® 4056, 5556, 7246, and 8238 (Injection Molded Test Pieces)

	Hytrel® 4056			Hytrel® 5556			Hytrel® 7246			Hytrel® 8238		
Letdown	—	12:1	10:1	—	12:1	10:1	—	12:1	10:1	—	12:1	10:1
% 52FR Concentrate	0	5.2	6.1	0	5.2	6.1	0	5.2	6.1	0	5.2	6.1
Oxygen Index[a], % (ASTM D 2863)	19.1	26.0	25.9	20.0	24.3	25.2	20.6	26.3	23.3	21.5	21.9	20.1
Vertical Burn (ASTM D 3801) Thickness 3.06 mm (1/8")	HB	V-2	V-2	HB	V-2[b]	V-2	HB	V-2	V-2[b]	HB	V-2	V-2
1.57 mm (1/16")	HB	V-2	V-2	HB	V-2[b]	V-2	HB	V-2	V-2	HB	V-2	V-2
0.8 mm (1/32")	HB	V-2	V-2	HB	V-2	V-2	HB	V-2	V-2	HB	V-2	V-2
Hardness Durometer D (ASTM D2240)	43	52	50	58	60	58	71	72	72	80	75	72
Tensile Strength, MPa (ASTM D 638)	23	20	20	31	27	30	37	27	31	39	31	33
Elongation at Break, % (ASTM D 638)	551	625	618	482	470	514	381	287	326	295	252	285
Flex Modulus, MPa (ASTM D 790)	81	155	164	212	269	280	680	746	761	1180	1586	1500
Melt Flow, g/10 min. (ASTM D 1238)	5.2	0.5	—[c]	7.8	10	8.6	13	14	16	21	20	20
Condition, at °C and 2.16 Kg load	190	190	190	220	220	220	240	240	240	240	240	240

a Values measured by D2863 are not intended to reflect hazards presented by this or any other material under actual fire conditions.
b Ret. UL Listing Card, Guide QMQS2, File No. E63766.
c No flow (with 52FR addition to Hytrel® 4056 the melt flow at 190 C was very low/or the melt did not flow at all due to the Hytrel® 5556 base in 52FR with higher melting characteristics). Note: 52FR is not optimized for Hytrel® resins with Durometer hardness of less than 55D.

Table 6.6 Heat Aging: Blends of 52FR in Hytrel® 5556, 7246 and 8238 (Injection Molded Test Pieces)

Polymer	Hytrel® 5556			Hytrel® 7246			Hytrel® 8238		
Letdown	—	12:1	10:1	—	12:1	10:1	—	12:1	10:1
% 52FR Concentrate	0	5.2	6.1	0	5.2	6.1	0	5.2	6.1
Original Properties									
Tensile Strength, MPa (ASTM D 638)	31	27	30	37	27	31	39	31	33
Elongation at Break, % (ASTM D 638)	482	470	514	381	287	326	295	252	285
Melt Flow, g/10 min. (ASTM D 1238)	7.8	10	8.6	13	14	16	21	20	20
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 100°C (212°F) - 2 weeks (336 hr)									
Tensile Strength, MPa (ASTM D 638)	29	22	27	36	29	34	33	37	30
Elongation at Break, % (ASTM D 638)	480	350	500	333	290	302	383	280	420
Melt Flow, g/10 min. (ASTM D 1238)	9.0	10	9.3	14	14	15	15	14	15
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 100°C (212°F) - 4 weeks (672 hr)									
Tensile Strength, MPa (ASTM D 638)	30	25	24	40	29	34	43	41	40
Elongation at Break, % (ASTM D 638)	483	470	473	410	333	316	294	249	215
Melt Flow, g/10 min. (ASTM D 1238)	9.2	11	10	16	15	16	16	14	15
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 100°C (212°F) - 6 weeks (1008 hr)									
Tensile Strength, MPa (ASTM D 638)	28	25	27	35	30	35	41	41	41
Elongation at Break, % (ASTM D 638)	483	466	505	400	337	310	355	225	249
Melt Flow, g/10 min. (ASTM D 1238)	10	12	12	16	17	18	22	20	19
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 125°C (257°F) - 2 weeks (336 hr)									
Tensile Strength, MPa (ASTM D 638)	28	24	25	39	—	34	31	31	42
Elongation at Break, % (ASTM D 638)	481	495	523	330	—	340	346	100	<50
Melt Flow, g/10 min. (ASTM D 1238)	14	15	13	22	—	20	17	23	27
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 125°C (257°F) - 4 weeks (672 hr)									
Tensile Strength, MPa (ASTM D 638)	29	25	25	41	32	33	38	31	42
Elongation at Break, % (ASTM D 638)	525	516	532	463	369	341	322	<50	<50
Melt Flow, g/10 min. (ASTM D 1238)	17	16	16	31	24	24	22	26	26
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 125°C (257°F) - 6 weeks (1008 hr)									
Tensile Strength, MPa (ASTM D 638)	27	22	23	34	23	36	29	41	43
Elongation at Break, % (ASTM D 638)	552	491	486	391	360	354	249	<50	<50
Melt Flow, g/10 min. (ASTM D 1238)	TF	TF	TF	35	26	30	45	41	30
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 135°C (275°F) - 2 weeks (336 hr)									
Tensile Strength, MPa (ASTM D 638)	29	23	22	39	26	35	31	42	43
Elongation at Break, % (ASTM D 638)	557	505	444	451	—	340	<50	<50	<50
Melt Flow, g/10 min. (ASTM D 1238)	17	17	15	23	27	24	18	43	49
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 135°C (275°F) - 4 weeks (672 hr)									
Tensile Strength, MPa (ASTM D 638)	16	16	16	23	22	25	23	38	43
Elongation at Break, % (ASTM D 638)	<50	93	90	297	331	355	76	<50	<50
Melt Flow, g/10 min. (ASTM D 1238)	TF	TF	TF	50	51	54	23	44	58
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Heat Aging at 135°C (275°F) - 6 weeks (1008 hr)									
Tensile Strength, MPa (ASTM D 638)	failed	failed	failed	31	28	25	27	32	39
Elongation at Break, % (ASTM D 638)	failed	failed	failed	<50	<50	56	<50	<50	<50
Melt Flow, g/10 min. (ASTM D 1238)	—	—	—	60	64	66	53	58	61
Condition, at °C and 2.16 Kg load	220	220	220	240	240	240	240	240	240
Comment on discoloration after aging	pink	no	no	pink	no	no	pink	no	no

Note: Hytrel® 5566, 7246 and 8238 samples after oven aging showed pink discoloration, while the same containing 52FR showed no discoloration

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 6.7 offers some general guidelines to assist in selecting the grade of Hytrel® for an intended 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 generally address end-use environments is rated 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 and/or chemicals).

The highest 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 6.7 Fluid Resistance

	Hardness		
	30D-40D	45D-55D	63D-83D
Mineral oils and greases, other nonaromatic hydrocarbons	Very suitable	Very suitable	Very suitable
Benzene, toluene, other aromatic hydrocarbons, chemicals and solvents	Not suitable	Generally suitable	Very suitable
Water, alcohols, glycols			
• Ambient temperature	Very suitable	Very suitable	Very suitable
• >50°C (>122°F)	Not suitable	Not suitable	Not suitable
Acids and bases			
• Diluted	Generally suitable	Very suitable	Very suitable
• Concentrated	Not suitable	Not suitable	Not suitable

- 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 6.8**).

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 6.8 Permeability[a] of Hytrel® to Gases

Gas	Hytrel® 4056	Hytrel® 5556	Hytrel® 6356	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}	0.8×10^{-8}
Freon® 22 Fluorocarbon	0.5×10^{-8}	0.6×10^{-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: cm3 (at standard temperature and pressure, STP) mm/Pa s m2 at 21.5°C and P = 34.5 kPa or cm3 (at STP) cm/atm sec cm2 at 71°F and P = 5 psi

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

Radiation Resistance

The use of nuclear energy, for example in power plants, military areas, and medicine, places requirements on many rubber compounds as well as other materials. Some factors of importance 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.

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 crosslinks 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 crosslinked 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.

Three uncompounded grades of Hytrel® polyester elastomer show excellent retention of physical properties after irradiation at 23°C (73°F) in air, as seen in **Table 6.9**. The exposure to 150 kJ/kg (15 Mrad) produces very little change in the properties of Hytrel®. (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.

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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 6.9 - 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 evaluated according to ASTM G21, 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 resistance, because they are based on the same raw materials.

Section 7 - Regulatory

For selected specific application areas, DuPont has developed information which will help enable the product user to obtain approvals for their application from authorities or to certify compliance with regulations, industry standards and requirements. These areas include:

Electrical and Electronic Applications

Material classifications by Underwriters' Laboratories, Inc.

UL listings ('yellow cards') for many DuPont resins are available through UL (www.ul.com). These listings typically show flammability ratings, electrical and mechanical properties and relative thermal indices.

Food Contact/Drinking Water/Food Processing Equipment/Healthcare Applications

Statements

Statements can be requested from your local DuPont representative for those resins which comply with relevant regulations and/or testing protocols such as those listed below.

Food Contact Regulations

USA:

FDA 21 CFR 177.1590 / 21 CFR 177.2600 (US Food and Drug Administration, Department of Health and Human Services).

Europe:

The EU (European Union) Regulation No10/2011 and its related regulations plus country specific regulations where applicable.

Canada:

HPB (Health Protection Branch of Health and Welfare).

China:

Chinese regulation GB9685-2008

Drinking Water Application Regulations

USA:

NSF International (NSF/ANSI Standard 61).

Germany:

KTW (Kunststoff-Trinkwasser-Empfehlungen)

United Kingdom:

WRAS (Water Regulations Advisory Scheme)

France:

ACS (Attestation de Conformité Sanitaire)

Food Processing Equipment Regulations

NSF International (NSF/ANSI 51) or USDA (United States Department of Agriculture).

Health Care Regulations

Application or Grade specific.

Regulated and Declarable Chemicals

Statements as required to meet specific local, regional or global regulations and industry requirements can be requested by contacting your DuPont representative.

General

DuPont will adapt its products to the changing market needs or develop new products to satisfy new regulatory requirements. The same is true for information needed to support customers for regulatory compliance of their applications.

Consult with your DuPont representative on any questions you may have about the regulatory status of specific Hytrel® grades.

Section 8 – Applications

General Considerations

The following general stepwise procedure is intended to help minimize problems during the development 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, although this list is not intended to be exhaustive of all design considerations.

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 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 application 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 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 or ISO, 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, but may also need to include additional items based on end-use needs.

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 are property data and effect of environment.

Whereas property data in this guide 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 can 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:

$$\sigma = MZ/I$$

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

Calculating the bending moment:

$$M = Fl/4$$

where F = load
l = length of beam between supports

Therefore, $M = (135)(165)/4$
$= 5569$ N mm

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

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

Finally, calculating the stress,

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

Referring to **Figure 2.47**, 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:

$$Y \text{ max.} = Fl^3/(48\,EI)$$

where Y max. = deflection at center of beam
E = Young's modulus. In this case, the modulus determined from **Figure 2.47** is to be used.

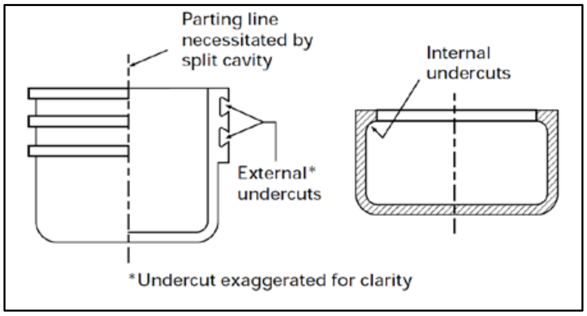
Therefore, $Y \text{ max.} = (135)(165)^3/48(126)(8464)$
$= 11.8$ mm

Hytrel® 6356 will meet the sag 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 8.1**).

Figure 8.1 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

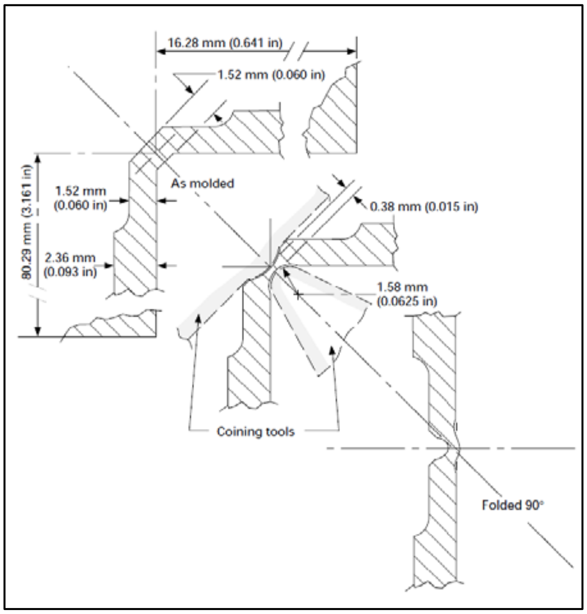
A Coined Hinge

Coining can be used as an assembly method. In **Figure 8.2**, 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 8.3** 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 8.2 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 canister 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 8.4** 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 8.3 Designing for Ultrasonic Assembly (Automotive Valve Component)

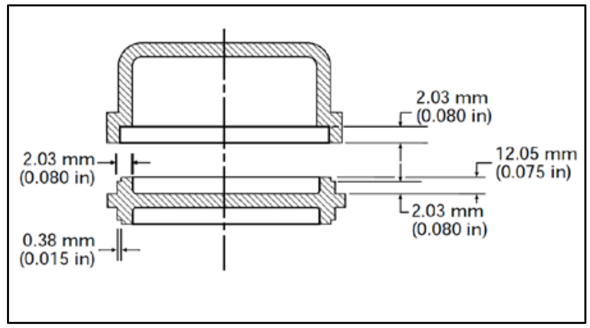
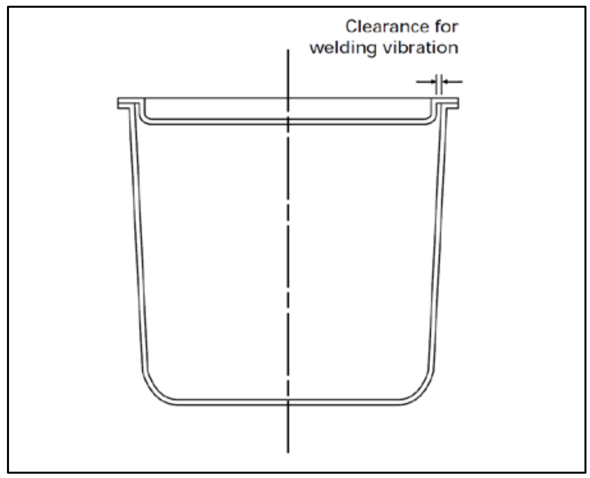


Figure 8.4 Design for Vibration Weld Assembly



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 8.1**).

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 8.2**).

Table 8.1 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®."

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 8.1**). If open time exceeds 4 hr, there will be essentially no adhesion between Hytrel® and the metal insert.

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 8.2 – 8.3**). 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).

Table 8.2 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

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 8.2**). Bond strength tends to be greater for the lower hardness polymers and decreases slightly as polymer hardness increases.

Table 8.3 Effect of Polymer and Metal Type on Bond Strength

Polymer	Substrate	Bond Strength (90° peel), kN/m (lb/in)
40D Hytrel®	Steel Aluminum Brass Stainless Steel	12.8 (73) 8.1 (46) 14.7 (84) 14.9 (85)
55D Hytrel®	Steel Aluminum Brass Stainless Steel	9.6 (55) 7.0 (40) 12.3 (70) 11.4 (65)
63D Hytrel®	Steel Aluminum Brass Stainless Steel	5.1 (29) 5.2 (30) 8.8 (50) 9.5 (54)
72D Hytrel®	Steel Aluminum Brass Stainless Steel	5.2 (30) 2.3 (13) 7.9 (45) 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 8.3**. 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 406 primer.

Substrate Type and Temperature

Excellent adhesion between Hytrel® and brass or steel is obtained with Thixon™406 (**Table 8.4**). 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 8.4 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 [535°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 light-weight. It is convenient to use for field (i.e., on-site) welding 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, G4074, 5556. Very high or very low melt flow grades (e.g., 5526 and HTR4275) 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.

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 x 12 mm (5.9 in x 0.5 in) (i.e., 1800 mm2 [2.95 in2]).
• 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 (570°F) with melt and weld times of 7–9 sec.

Good Weld	Questionable	No Weld
Polycarbonate	Styrene	ABS
SAN	Polyether sulphone	Polypropylene
Cellulose acetate	EVA	Nylon 66
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 (55°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 8-5 and 8-6**). 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 8.5 PV Limit and Wear Factor, ASTM D 3702, SI Units

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

Table 8.6 PV Limit and Wear Factor, ASTM D 3702, English Units

	PV Limit	Wear Factor, K
Type of Hytrel	$\frac{lb}{in^2} \times \frac{m}{min}$	$\frac{mm^3 \cdot min}{m \cdot N/hr} \times 10^{-10}$
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 8.5 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 8.6**. 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 8.5 Automotive CVJ Boot

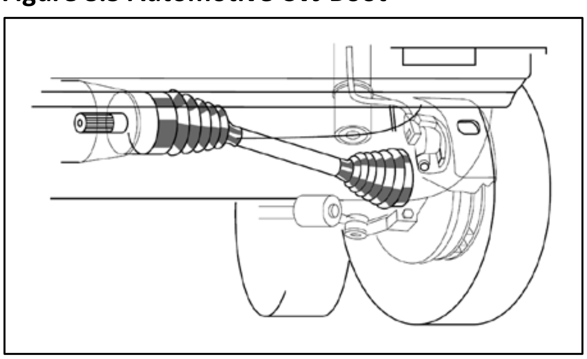
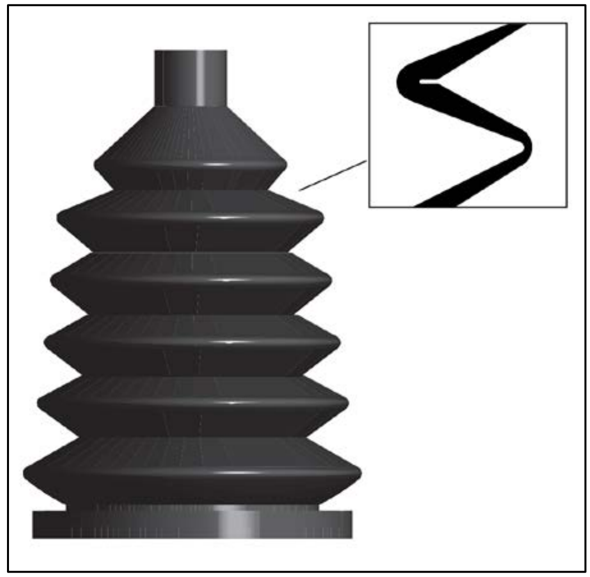


Figure 8.6 Boot Design



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 8.7** 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 8.8**.
- 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.

Figure 8.7 Rolling Type Diaphragm

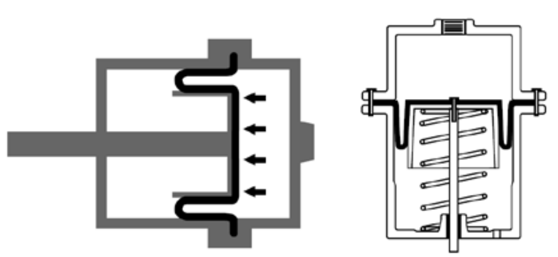


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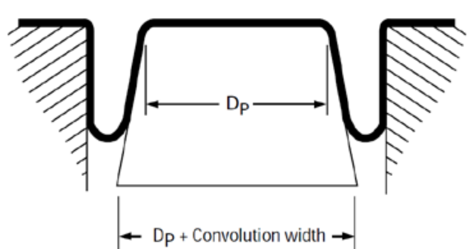
Figure 8.8 Tapered Piston Skirt



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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.

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 8.7**. 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 8.7 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® 21UV, 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 Section 6 - Effect of Environment).

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 thermo-plastic 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 Section 2). 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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(011/13) Reference number HYE-A11157-00-C0915