DESIGNING WITH FIBER REINFORCED AND INTERNALLY LUBRICATED THERMOPLASTIC ELASTOMERS

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INTRODUCTION

The recent introduction of many new thermoplastic elastomers has augmented the previously available thermoplastic urethanes and broadened the spectrum of properties available in these materials. The thermoplastic elastomer resins offer toughness, low temperature flexibility, moderate abrasion resistance, chemical resistance, moderate service temperature capability, weatherability, a broad hardness range (without plasticizers), and the ease of processing associated with injection molding. Most thermoplastic elastomers however, suffer major limitations in their ability to support loads, resistance to elevated temperature, resistance to permanent deformation, load/elongation relationships, flammability resistance and abrasion resistance. A series of reinforced and lubricated thermoplastic elastomer resin compounds designed to take advantage of the base resin attributes and overcome some of the limitations were developed. The development of elastomeric compounds with significantly reduced surface resistivity would allow for the design of "plastic" components incorporating toughness and the ability to dissipate static charge. Several flame-retardant glass fiber reinforced grades of elastomers have been developed to increase design freedom into areas requiring flammability resistance.

Property/Polymer Structure Relations

Thermoplastic elastomers share the processing ease of thermoplastic resins and the mechanical properties of rubbers. They may be melt-processed repeatedly by normal injection molding or extrusion techniques. They may be stretched repeatedly to twice their original length and upon immediate release will return to their original length. In contrast to rubbers which are cross-linked in a vulcanization step, the thermoplastic elastomers are linear polymer chains. In contrast to thermoplastics, their normal use temperature is above their glass transition temperature (Tg) rather than below it.

If an elastomer is used below its Tg, it becomes brittle and behaves like a normal thermoplastic. Thermoplastic elastomers can behave like rubbers because they have a similar physical structure. Microscopically the structure of vulcanized rubbers and thermoplastic elastomers are heterogeneous. They consist of highly ordered regions interspersed regularly with amorphous regions. In rubbers, the order is maintained by cross-linking. In elastomers, the order is maintained by the crystallinity of certain segments of the polymer chain. The ordered regions tend to absorb stresses and rather than transmit them in a linear fashion, they transmit them by branching to the amorphous regions in a manner which prevents crack or craze propagation.

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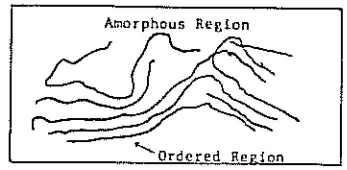
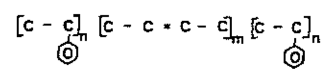
Figure 1:



The yield strength of an elastomer is associated with the more amorphous region. The ultimate strength is associated with the ordered region. A variety of chemical routes have been employed to produce linear polymer molecules which will form amorphous and ordered regions in the bulk state. Although not the earliest, the best defined and controlled method for preparing thermoplastic elastomers is through the formation of triblock copolymers. Triblock copolymers are easily formed by "living polymer" synthesis. To form a styrene-butadiene-styrene (SBS) copolymer, a short living styrene unit is formed. It is then "fed" butadiene monomer to form an SB diblock copolymer. The final SBS triblock copolymer is formed either by feeding more styrene or coupling two SB diblock copolymers together. Shell's Kraton® is an example of the latter. Polystyrene and polybutadiene are incompatible. If these homopolymers were mixed together they would separate into a bulk two-phase solid with little mechanical strength. In the case of the SBS triblock copolymers, however, the two incompatible polymers are bound together on one molecule and an ordered microscopic phase separation takes place.

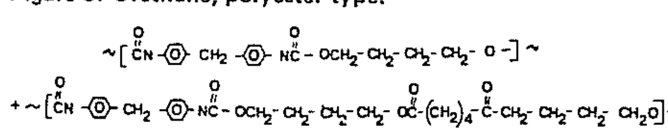
Figure 2: SBS



Urethanes were the first class of thermoplastic elastomers to be introduced. One dozen suppliers now make approximately thirty different grades. Urethanes are three-component condensation polymers. One of the components, a diisocyanate, can react with either of the two remaining components, a small glycol molecule, or a longer dialcohol molecule. The reaction product is called a urethane. When the small glycol molecules are bound in urethane linkages they form rigid chain segments which are attracted to one another through hydrogen bonding. They form semi-crystalline regions which are said to be "virtually cross-linked". The urethane-linked large dialcohol molecules have little opportunity for hydrogen bonding and form an amorphous matrix.

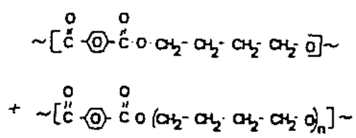
Two different classes of thermoplastic polyurethanes are available, polyesters and polyethers. The distinction is based on differences between the long dialcohol molecules. The long dialcohol can be made by forming an ester of two small glycols with a diacid or by forming an ether of two small glycols. In general, ether chemistry is more expensive and leads to polymers with greater hydrolytic and thermal stability, and increased flexibility. It is difficult, however, to prejudge the relative stability and properties of a polyether urethane vs. a polyester urethane from a different supplier since the diisocyanate, glycol and dialcohol molecules are usually different and are present in different ratios. Typical diisocyanates are toluene diisocyanate (TDI) used for example in Mobay's Texin® and diphenylmethane diisocyanate (MDI) used in UpJohn's Pellethane®. Butanediol and ethylene glycol are the frequently used glycols for the hard segments of the urethanes. Tetramethylene adipate glycols, tetramethylene ether glycols and polycaprylactones are employed for the soft segments.

Figure 3: Urethane, polyester type.



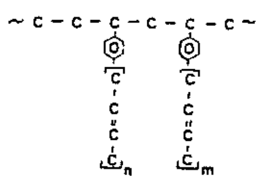
Hytrel® is duPont's tradename for a series of polyester elastomers based on terephthalic acid, butanediol ethers, usually called polytetramethylene ether glycol (PTMEG). These copolymers possess a two-phase structure. The amorphous segments formed by PTMEG, contribute to the elastomeric character of the polymer, whereas the crystalline segments serve as the thermally reversible "virtual crosslinks" which account for the mechanical strength. When 58% of the diol portion of the PBT elastomer is butanediol, the PBT elastomer's durometer hardness is 55D. It has a Tg of 50°C and a melt point of 202°C. If the butanediol is increased to 76% of the glycol portion of the PBT elastomer, the durometer hardness increases to 63D and the meltpoint increases to 212°C.

Figure 4: PBT Elastomer



While a variety of graft copolymers are available, the only material which displays the properties of a thermoplastic elastomer is polyethylene grafted with polybutylene through a phenolic linkage. This material was first developed by W. R. Grace and is now offered by Allied as ET Polymer®. Levels of 25% and 50% polybutylene grafted onto low or high density polyethylene are available. The materials are the "least elastic" of the elastomers and do not demonstrate characteristic Tgs although their Tgs appear reduced to between -14°C to -40°C.

Figure 5: ET



Olefin rubbers are generally prepared from propylene and/or ethylene and one other monomer or cross-linking agent. They differ from EPDM since they are not cross-linked into thermoset rubbers. Somel® is an olefin rubber manufactured by DuPont. TPR® is an ethylene block copolymer manufactured by Uniroyal.

Blends

While two non-compatible polymers cannot be blended to form an elastomer, a block polymer elastomer can be blended with a polymer that is compatible with one of its blocks. As long as the virtual cross-linking remains, the blends will continue to exhibit elastomeric behavior. Blending efficiency is extremely important, the maximum particle size of an EPDM particle for preparation of a tough propylene blend is 0.5*u* Telcar® manufactured by Goodrich, is an example of an elastomer blend.

The most conspicuous functional role of thermoplastic elastomers is to provide toughness in a part design. Associated with this physical property are the mechanical properties of impact strength, ductility and tear resistance. An unrelated functional characteristic is the high coefficient of friction of the elastomers which allows their performance as braking components. The nature of the chemistry which created these materials also leads to certain deficiencies which limit their utility. In particular, these deficiencies include low dimensional stability, reduced strength and modulus limited high temperature properties, poor wear and flammability resistance. The improvement of properties in any of these areas would extend the utility of the thermoplastic elastomers.

A variety of fillers are available for reinforcing thermoplastics which provide increased dimensional stability, modulus and high temperature properties. The fillers do not impart changes in physical properties to elastomers in the same manner as thermoplastics, since the elastomers are already heterogeneous materials to begin with. If the filler changes the characteristics of one of the elastomer phases, the elastomer can lose toughness. Particulate fillers are likely to upset phase balance before they effect improvements in modulus. Reinforcements with high critical aspect ratios have a much higher reinforcement efficiency and are more likely to promote the desired modulus increases without unduly modifying the elastomer phases.

Since elastomers inhibit craze and crack propogation by concentrating the energy in rubbery regions and subsequently branching them into smaller energy components which the matrix can withstand, any mechanism which makes crack propagation linear, will mitigate the effect of the rubbery regions. Since at high concentrations, fibers overlap and produce this situation, loadings over 15% by weight are to be avoided if toughness must be maintained.

Olefin Rubber Composites

Low and high modulus olefin rubber resins were evaluated as neat resins and as composites with the addition of 5% and 20% glass fiber reinforcement (Figure 6). The addition of glass fiber reinforcement results in increased hardness, lower elongation, slightly increased tensile strength, increased flexural modulus, increased flexural strength and higher heat distortion temperature but lower elongation and decreased impact strength.

A range of flexural modulus values from 25,000 psi for the low modulus neat resin, to 190,000 psi for the 20% glass fiber reinforced high modulus resin can be attained. Tensile strength values ranged from 1,450 psi for the neat low modulus resin, to 2,800 psi for the 20% glass fiber reinforced high modulus resin.

A medium modulus olefin rubber was also evaluated as the neat resin and as a composite with the addition of 5% and 20% glass fiber reinforcement (Figure 7). The olefin rubber resin appears to reinforce more efficiently with glass fibers resulting in a higher tensile strength, 3,800 psi in the 20% glass fiber reinforced composite, and a greater decrease in impact strength than the ethylene propylene block copolymer resin composites.

A series of bronze powder filled and carbon fiber reinforced olefin rubber resins were evaluated as electrically conductive thermoplastic elastomer composites. The 75% bronze filled olefin rubber (PDX-5294) yields a surface resistivity of 10^5 ohms/sq while retaining an unnotched Izod impact strength value greater than 40 ft lbs/in. This composite retains many of the attributes of elastomeric materials (toughness, low modulus, high elongation) while offering the ability to dissipate static charge.

The 85% bronze filled olefin rubber composite (PDX-5296) offers a significantly reduced surface resistivity (1,500 ohms/sq) but suffers a decrease in unnotched Izod impact strength to 3.2 ft lbs/in.

The 15% carbon fiber reinforced olefin rubber composite also possesses the ability to dissipate static charge with a surface resistivity of 500 ohms/sq. The composite offers improved tensile strength, flexural modulus and heat distortion temperature, and outstanding toughness for a carbon fiber reinforced composite. Electrical conductivity can be either an advantage or a disadvantage, depending upon the requirements of the application. It can be used to advantage for electromechanical components where static-charge dissipation is needed. Examples include gears, bearings, and structural members for business machines, textile and other web-type processing equipment, and rotating machinery in general. On the other hand, the carbon-fiber composites would not be suitable for a housing for an electric drill or other components where electrical insulation is required. An alternative is the addition of carbon black to make the compound conductive. While carbon black is inexpensive, loadings as high as 30% are needed to accomplish conductivity — an amount that degrades other properties appreciably.

Polyester Elastomer Composites

A series of glass fiber reinforced polyester elastomer composites were prepared with 5% through 30% glass fiber content in two neat base resin grades with flexural modulus values of 25,000 psi (standard grade) and 75,000 psi (high modulus grade). The Shore D hardness of the 30% glass reinforced polyester elastomer composite is increased 16 points while a four-fold increase in tensile strength, a greater than ten-fold increase in flexural modulus, a five-fold reduction in mold shrinkage and a three-fold increase in heat distortion temperature are observed over the neat base polyester elastomer resin. However, the composite does suffer a greater than five-fold decrease in tensile impact strength and an extremely severe loss of elongaton (Figure 9).

The lower glass content range (5%-20%) polyester elastomer composites however, offer property improvements and reductions intermediate to the neat base resin and the 30% glass fibers reinforced polyester elastomer composite.

A series of low aspect ratio fillers were incorporated into the polyester elastomer resin to improve dimensional stability, reduce mold shrinkage anisotropy and increase flexural modulus, while maintaining a greater measure of toughness (Figure 10) than the glass fiber reinforced analogs.

The 30% milled glass fiber, 30% glass bead and 40% mineral filled polyester elastomer composites yield diminished physical property and dimensional stability improvements when compared to glass fiber, but do result in composites with good toughness.

The glass fiber reinforced polyester elastomer composites offer the greatest "engineering plastic capabilities" of the thermoplastic elastomers because of their superior elevated temperature performance. The polyester elastomers offer a combination of elevated temperature performance and excellent toughness.

Thermoplastic Polyurethane Composites

A series of reinforced thermoplastic polyurethane composites with glass fiber contents ranging from 5% to 40% have been evaluated.

The addition of glass fiber reinforcements to polyurethane results in significant increase in tensile strength from 2,000 psi for the neat base resin to 9,600 psi for the 40% glass fiber reinforced grade (Figure 11). Flexural modulus values ranged from a low of 15,000 psi for the base polyurethane resin to a high of 260,000 psi for the 40% glass fiber reinforced composite. The heat distortion temperature at 264 psi can be increased two-fold with glass fiber addition, while the 24 hr. water absorption can be halved. The addition of 40% glass fiber to polyurethane results in a three-fold decrease in mold shrinkage values and an increase of 16 points in Shore D hardness. The decrease in unnotched Izod impact strength associated with the addition of glass fibers is gradual and demonstrates a relatively high level of toughness at the high reinforcement levels. The high tensile impact strength values for polyurethane are also maintained at the high reinforcement loadings. The glass fiber reinforced polyurethane composites present a property profile closely related to the traditional reinforced engineering thermoplastic resins.

SBS Block Copolymer Composites

The addition of 20% glass fiber reinforcement to SBS block copolymer resin results in a composite displaying slightly decreased tensile strength, a Shore D hardness increase of 18 points, a two-fold reduction in mold shrinkage, slight decreases in tensile elongation and tensile impact strength and only a slight increase in heat distortion temperature at 66 psi. The large increase noted in 24 hr. water absorption and the decrease in tensile strength indicate that the glass fibers are not coupling to the resin and are acting merely as an extending filler. The flexural modulus of the neat base resin and the 5% and 20% glass fiber reinforced SBS composites could not be measured at room temperature by the ASTM D-790 test method because of immediate deformation upon application of load.

Butyl Grafted Polyethylene Composite

The addition of glass fiber reinforcement to butyl grafted polyethylene elastomer results in a composite with significantly reduced mold shrinkage, increased flexural modulus, increased tensile strength and flexural strength while exhibiting only moderate decreases in impact strength (Figure 13). The butyl grafted polyethylene neat base resin exhibits only 70% elongation, tensile impact strength of 170 ft lbs/in^2, and a very high mold shrinkage of 0.026 in/in.

Flame Retardant, Glass Fiber Reinforced Elastomer Composites

30% glass fiber reinforced, flame retardant polyester elastomer and 30% glass fiber reinforced, flame retardant thermoplastic polyurethane composites were prepared for applications requiring 94VO listing according to Underwriters' Laboratories Subject 94 test method. The addition of flame retardant additives to glass reinforced thermoplastic polyurethane and glass reinforced polyester elastomer results in a moderate decrease in tensile strength, impact strength, and heat distortion temperature but results in composites with a 94VO listing by Underwriters' Laboratories Subject 94 test method and limiting oxygen index values over 30 (% O_2) by the ASTM-D2863 test method.

Wear Resistance and Frictional Properties of Internally Lubricated Elastomer Composites

A series of PTFE and silicone lubricated thermoplastic elastomers were compared for wear resistance and coefficient of friction. The addition of glass fibers and internal lubricants (PTFE, silicone) to thermoplastic elastomers results in large reductions in wear rate and coefficient of friction. The addition of 15% PTFE lubricant to olefin rubber results in a halving of the wear rate and a substantial reduction in dynamic coefficient of friction (Figure 15). The addition of 15% PTFE lubricant to SBS block copolymer does not effect a significant reduction in wear rate, but does result in a reduced coefficient of friction. The 30% glass reinforced, 15% PTFE lubricant thermoplastic polyurethane composite results in a ten-fold reduction in wear factor and a significant decrease in coefficient of friction. The addition of glass fibers, silicone, and PTFE to the polyester elastomer resin results in a composite exhibiting lowered coefficients of friction and wear factors reduced up to 200-fold (Figure 15).

Abrasion Resistance of Glass Fiber Reinforced Elastomer Composites

The addition of 20% glass fiber to olefin rubber, butyl grafted polyethylene, thermoplastic polyurethane and polyesters, resulted in decreased abrasion resistance to a Taber CS-17 wheel at 1,000 cycles with a 1000 gr applied load (Figure 16). The effect of the addition of internal lubricant to thermoplastic elastomers will be investigated in the future to determine whether increased abrasion resistance can be achieved.

Effect of Strain Rate on Tensile Properties

The tensile properties of neat elastomer resins and the 5% and 20% glass fiber reinforced composites were examined at loading speeds of 2"/min and 20"/min corresponding to straining rates of 200%/min and 2,000%/min respectively. In general, the tensile strength values increase as the loading speed is increased and the tensile elongation values decrease as loading speed is increased. The only exception to this was the increased tensile elongation at higher loading speeds noted for the SBS block copolymer resins (Figures 17-18). The neat polyurethane base resin demonstrated the greatest tensile strength rate dependency, while the neat SBS block copolymer resin and composites exhibits the least. The neat polyurethane resin and the 5% glass reinforced polyester elastomer composite demonstrated the largest tensile elongation straining rate response with decreases of 37% and 66% respectively noted between the 200%/min and 2000%/min straining rates (Figure 17). The low modulus neat olefin rubber resin and composites demonstrate the greatest tensile strength straining rate dependency, while the high modulus neat olefin rubber resin and composites demonstrate the greatest tensile elongation straining rate dependency (Figure 18).

Effect of Elevated Temperature on Tensile Properties

The tensile strength of neat olefin rubber resin, polyurethane resin, polyester elastomer resin and the respective 5% and 20% glass reinforced composites was gathered at 75°F and 140°F with a loading speed of 2"/min. The polyurethane resin composites exhibit the largest decrease in tensile strength while the polyester elastomer resin composites evidence small decreases in tensile strength up to 140°F (Figure19).

Creep Resistance

Creep is defined as the total deformation produced in a viscoelastic body by the application of stress. It contains a purely elastic, constant component (the instantaneous value of the modulus of elasticity) and a time-dependent, slowly increasing component, (the creep function). The total deformation under constant load is the sum of these components. Creep data is presented as total strain at a constant applied stress in flexure at 73°F for center loaded 1/8" x 1/4" x 5" specimens suspended over a 4" span. The 20% glass reinforced polyester elastomer exhibits excellent creep resistance with a total creep strain of 1.35% after 1000 hours at an applied stress of 2,000 psi at room temperature (Figure 20). The 30% glass reinforced polyester elastomer exhibits a total creep strain of 0.80% after 1,000 hours at an applied stress of 2,000 psi at room temperature and a total creep strain of 0.40% after 1,000 hours at an applied stress of 1,000 psi at room temperature. The 40% glass reinforced polyurethane also demonstrates improved creep resistance with a total creep strain of 0.41% after 1,000 hours at an applied stress of 500 psi at room temperature and a total creep strain of 0.87% after 1,000 hours at an applied stress of 1,000 psi at room temperature (Figure 21).

CONCLUSIONS

1. The hardness of a thermoplastic elastomer can be increased significantly with the addition of fiber reinforcement.
2. Thermoplastic elastomer composites suitable for dissipating static charges can be prepared with the addition of bronze powder or carbon fiber.
3. Thermoplastic elastomer composites with significantly enhanced wear resistance and reduced coefficient of friction can be prepared with the addition of PTFE and silicone lubricants.
4. The addition of glass fiber reinforcement results in significant increases in flexural modulus in thermoplastic elastomer composites.
5. The addition of glass fiber reinforcement to thermoplastic elastomers results in significant decreases in mold shrinkage.
6. Significant increases in heat distortion temperature and enhanced elevated temperature performance can be effected with the addition of glass fiber reinforcement to thermoplastic elastomers.
7. Improved creep resistance can be accomplished with the addition of glass fibers to thermoplastic elastomers.
8. Flame-retardant glass fiber reinforced polyurethane and polyester elastomer composites can be prepared with a high physical property level.

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Figure 6

PHYSICAL PROPERTIES OF GLASS FIBER REINFORCED OLEFIN RUBBER

Property	ASTM Method	Units	Olefin Rubber Base Resin	PDX-5277 (5% Glass)	PDX-5278 (20% Glass)	Olefin Rubber High Modulus	PDX-5228* (5% Glass)	PDX-5229* (20% Glass)
Specific Gravity	D-792	–	0.88	0.91	1.01	0.89	0.92	1.02
Hardness, Shore D	D-2240	Points	43	47	53	52	55	62
Water Absorption, 24 hrs.	D-570	%	0.03	0.03	0.03	0.03	0.03	0.03
Mold Shrinkage	D-955	in/in	0.0085	0.008	0.006	0.008	0.007	0.005
Tensile Yield Strength, 2"/min	D-638	psi	1,450	1,450	1,500	2,400	2,450	2,800
Tensile Elongation, 2"/min	D-638	%	175	90	50	70	40	20
Flexural Strength	D-790	psi	1,100	1,200	1,750	2,300	2,800	3,100
Flexural Modulus	D-790	psi	25,000	55,000	100,000	55,000	90,000	190,000
Tensile Impact Strength	D-1822	ft lbs/in^2	260	140	70	200	85	50
Izod Impact Strength	D-256	ft lbs/in						
Notched, 1/4" Bar			>40	>40	>40	>40	>40	8
Unnotched, 1/4" Bar			>40	>40	>40	>40	>40	12
Heat Distortion Temperature	D-648	°F						
66 psi			120	125	125	180	190	220
264 psi			85	95	100	90	120	125

* High Modulus Base Resin

Figure 7

PHYSICAL PROPERTIES OF GLASS FIBER REINFORCED OLEFIN RUBBER

Property	ASTM Method	Units	Olefin Rubber Base Resin*	PDX-5159* (5% Glass)	PDX-5160* (20% Glass)
Specific Gravity	D-792	-	0.89	0.92	1.02
Hardness, Shore D	D-2240	Points	47	52	57
Water Absorption, 24 hrs.	D-570	%	0.01	0.01	0.02
Mold Shrinkage	D-955	in/in	0.007	0.006	0.005
Tensile Yield Strength, 2"/min	D-638	psi	2,100	2,500	3,800
Tensile Elongation, 2"/min	D-638	%	500	30	20
Tensile Yield Strength, 20"/min	D-638	psi	2,100	3,000	4,500
Tensile Elongation, 20"/min	D-638	%	325	25	15
Flexural Strength	D-790	psi	1,900	3,000	4,000
Flexural Modulus	D-790	psi	40,000	75,000	135,000
Tensile Impact Strength	D-1822	ft lbs/in^2	230	95	60
Izod Impact Strength	D-256	ft lbs/in			
Notched, 1/4" Bar			>40	8.0	6.0
Unnotched, 1/4" Bar			>40	20.0	12.0
Heat Distortion Temperature	D-648	°F			
66 psi			180	190	220
264 psi			90	120	125

* Medium Modulus Base Resin

Figure 8

PHYSICAL PROPERTIES OF CARBON FIBER REINFORCED AND BRONZE POWDER FILLED ELECTRICALLY CONDUCTIVE OLEFIN RUBBER

Property	ASTM Method	Units	PDX-5294 75% Bronze Olefin Rubber	PDX-5296 85% Bronze Olefin Rubber	PDX-5276 15% Carbon Fiber Olefin Rubber
Specific Gravity	D-792	-	2.70	3.75	0.97
Hardness, Shore D	D-2240	Points	53	57	53
Mold Shrinkage	D-955	in/in	0.007	0.006	0.006
Tensile Yield Strength, 2"/min	D-638	psi	700	600	1,400
Tensile Elongation, 2"/min	D-638	%	40	25	60
Flexural Strength	D-790	psi	1,150	1,100	1,500
Flexural Modulus	D-790	psi	55,000	70,000	95,000
Tensile Impact Strength	D-1822	ft lbs/in^2	40	30	45
Izod Impact Strength	D-256	ft lbs/in			
Notched, 1/4" Bar			5.0	1.4	>40
Unnotched, 1/4" Bar			>40	3.2	>40
Heat Distortion Temperature	D-648	°F			
66 psi			125	125	220
264 psi			90	90	100
Surface Resistivity		ohms/sq	10^5	1,500	500

Figure 9

PHYSICAL PROPERTIES OF GLASS FIBER REINFORCED POLYESTER ELASTOMERS

Property	ASTM Method	Units	Polyester Elastomer Base Resin	YF-1001 (5% Glass)	YF-1004 (20% Glass)	YF-1006 (30% Glass)	Polyester Elastomer High Modulus	YF-1001 H.M.* (5% Glass)	YF-1004 H.M.* (20% Glass)
Specific Gravity	D-792	-	1.20	1.23	1.34	1.42	1.22	1.25	1.38
Hardness, Shore D	D-2240	Points	54	58	64	70	72	74	78
Water Absorption, 24 hrs.	D-570	%	0.19	0.19	0.18	0.17	0.07	0.07	0.06
Mold Shrinkage	D-955	in/in	0.014	0.010	0.004	0.003	0.018	0.010	0.004
Tensile Yield Strength, 2"/min	D-638	psi	2,100	3,500	7,100	8,500	4,300	5,600	9,700
Tensile Elongation, 2"/min	D-638	%	500	300	12	8	350	120	8
Flexural Strength	D-790	psi	3,100	5,400	10,200	13,000	6,600	9,600	14,300
Flexural Modulus	D-790	psi	25,000	65,000	170,000	320,000	75,000	130,000	300,000
Tensile Impact Strength	D-1822	ft lbs/in^2	>320	95	75	60	>320	80	65
Izod Impact Strength	D-256	ft lbs/in							
Notched, 1/4" Bar			>40	9.0	8.0	5.0	>40	5.0	4.0
Unnotched, 1/4" Bar			>40	>40	20	16	>40	25	17
Heat Distortion Temperature	D-648	°F							
66 psi			315	355	385	385	330	400	400
264 psi			110	250	340	340	155	300	380

* High Modulus

Figure 10

PHYSICAL PROPERTIES OF POLYESTER ELASTOMER REINFORCED WITH LOW ASPECT RATIO FILLERS

Property	ASTM Method	Units	Polyester Elastomer Base Resin	YF-1006 M (30% Milled Glass)	YF-1006 B (30% Glass Beads)	YM-3480 (40% Mineral)
Specific Gravity	D-792	-	1.20	1.42	1.42	1.54
Hardness, Shore D	D-2240	Points	54	62	60	65
Mold Shrinkage	D-955	in/in	0.014	0.010	0.011	0.008
Tensile Yield Strength, 2"/min	D-638	psi	2,100	2,700	2,400	3,200
Tensile Elongation, 2"/min	D-638	%	500	70	250	40
Flexural Strength	D-790	psi	3,100	4,500	4,300	5,000
Flexural Modulus	D-790	psi	25,000	57,000	46,000	66,000
Izod Impact Strength	D-256	ft lbs/in				
Notched, 1/4" Bar			>40	5.5	5.0	5.0
Unnotched, 1/4" Bar			>40	>40	>40	>40
Heat Distortion Temperature	D-648	°F				
66 psi			315	350	340	350
264 psi			110	195	165	180

Figure 11

PHYSICAL PROPERTIES OF GLASS FIBER REINFORCED THERMOPLASTIC POLYURETHANE

Property	ASTM Method	Units	Thermoplastic Polyurethane Base Resin	TF-1001 (5% Glass)	TF-1002 (10% Glass)	TF-1004 (20% Glass)	TF-1006 (30% Glass)	TF-1008 (40% Glass)
Specific Gravity	D-792	-	1.25	1.28	1.32	1.37	1.46	1.55
Hardness, Shore D	D-2240	Points	54	56	58	60	65	70
Water Absorption, 24 hrs.	D-570	%	0.40	0.35	0.32	0.30	0.25	0.20
Mold Shrinkage	D-955	in/in	0.008	0.007	0.006	0.005	0.004	0.003
Tensile Yield Strength, 2"/min	D-638	psi	2,000	3,400	5,600	6,800	8,200	9,600
Tensile Elongation, 2"/min	D-638	%	510	270	200	30	25	20
Flexural Strength	D-790	psi	1,700	3,600	3,900	4,300	5,600	6,900
Flexural Modulus	D-790	psi	15,000	40,000	70,000	125,000	190,000	260,000
Tensile Impact Strength	D-1822	ft lbs/in^2	>320	190	160	130	120	100
Izod Impact Strength	D-256	ft lbs/in						
Notched, 1/4" Bar			>40	>40	11	10	9.5	9.0
Unnotched, 1/4" Bar			>40	>40	35	30	29	28
Heat Distortion Temperature	D-648	°F						
66 psi			145	205	240	310	315	320
264 psi			90	95	135	165	170	175

Figure 12

GLASS FIBER REINFORCED SBS BLOCK COPOLYMER

Property	ASTM Method	Units	SBS Block Copolymer Resin	PDX-5230 (5% Glass)	PDX-5231 (20% Glass)
Specific Gravity	D-792	-	0.93	0.96	1.06
Hardness, Shore A	D-2240	Points	45	62	73
Water Absorption, 24 hrs.	D-570	%	0.03	0.15	0.35
Mold Shrinkage	D-955	in/in	0.045	0.030	0.020
Tensile Yield Strength, 2"/min	D-638	psi	650	600	500
Tensile Elongation, 2"/min	D-638	%	1,000	850	700
Flexural Strength	D-790	psi	220	330	440
Tensile Impact Strength	D-1822	ft lbs/in^2	100	90	70
Izod Impact Strength	D-256	ft lbs/in			
Notched, 1/4" Bar			>40	>40	>40
Unnotched, 1/4" Bar			>40	>40	>40
Heat Distortion Temperature	D-648	°F			
66 psi			95	110	130
264 psi			<75	<75	<75

Figure 13

GLASS FIBER REINFORCED BUTYL GRAFTED POLYETHYLENE

Property	ASTM Method	Units	Butyl Grafted Polyethylene	PDX-5292 Butyl Grafted Polyethylene (5% Glass)	PDX-5293 Butyl Grafted Polyethylene (20% Glass)
Specific Gravity	D-792	-	0.94	0.97	1.04
Hardness, Shore D	D-2240	Points	58	61	64
Water Absorption, 24 hrs.	D-570	%	0.01	0.02	0.04
Mold Shrinkage	D-955	in/in	0.026	0.021	0.013
Tensile Yield Strength, 2"/min	D-638	psi	2,700	3,150	3,550
Tensile Elongation, 2"/min	D-638	%	70	40	30
Flexural Strength	D-790	psi	3,100	3,300	3,800
Flexural Modulus	D-790	psi	70,000	110,000	170,000
Tensile Impact Strength	D-1822	ft lbs/in^2	170	100	65
Izod Impact Strength	D-256	ft lbs/in			
Notched, 1/4" Bar			>40	>40	8
Unnotched, 1/4" Bar			>40	>40	>40
Heat Distortion Temperature	D-648	°F			
66 psi			180	230	260
264 psi			90	120	135

Figure 14

FLAME RETARDANT, GLASS FIBER REINFORCED ELASTOMERS

Property	ASTM Method	Units	TF-1006 30% Glass Reinforced Polyurethane	TF-1006 FR 30% Glass Reinforced Flame Retardant Polyurethane	YF-1006 30% Glass Reinforced Polyester Elastomer	YF-1006 FR 30% Glass Reinforced Flame Retarndant Polyester Elastomer
Specific Gravity	D-792	-	1.46	1.62	1.42	1.61
Mold Shrinkage	D-955	in/in	0.004	0.003	0.003	0.003
Water Absroption, 24 hrs.	D-570	%	0.25	0.28	0.17	0.19
Hardness, Shore D	D-2240	Points	65	72	70	72
Tensile Strength	D-638	psi	8,200	6,600	8,500	7,300
Tensile Elongation	D-638	%	25	10	8	5
Flexural Strength	D-790	psi	5,600	8,200	13,000	12,000
Flexural Modulus	D-790	psi	190,000	275,000	320,000	340,000
Izod Impact Strength	D-256	ft lbs/in				
Notched, 1/4" Bar			9.5	6.5	5.0	4.0
Unnotched, 1/4" Bar			29	22	16	14
Heat Distortion Temperature	D-648	°F				
66 psi			315	310	385	365
264 psi			170	165	340	320
Flammability	UL Sub. 94			94V0		94V0
	D-2863	$\%O_2$		31		30

Figure 15

WEAR RESISTANCE AND FRICTIONAL PROPERTIES OF INTERNALLY LUBRICATED THERMOPLASTIC ELASTOMERS

LNP Product Code	Base Resin	Glass Fiber Content %	PTFE/Silicone Lubricant Content %	PTFE Lubricant Content %	Silicone Lubricant Content %	Wear Factor $\frac{in^3 min \times 10^{-10}}{ft\ lb\ hr}$	Static Coefficient of Friction μ_S	Dynamic Coefficient of Friction μ_D	Test PV $\frac{ft\ lb}{in^2\ min}$
-	Olefin Rubber	-	-	-	-	40	0.36	0.53	20
PDX-5189	Olefin Rubber	-	-	15	-	20	0.33	0.41	20
-	Polyurethane	-	-	-	-	340	0.32	0.37	20
TL-4030	Polyurethane	-	-	15	-	60	0.27	0.32	20
TFL-4036	Polyurethane	30	-	15	-	35	0.20	0.25	40
-	Polyester Elastomer	-	-	-	-	1,000	0.27	0.59	20
YL-4030	Polyester Elastomer	-	-	15	-	40	0.22	0.25	20
YL-4410	Polyester Elastomer	-	-	-	2	30	0.21	0.22	40
YL-4510	Polyester Elastomer	-	5	-	-	5	0.20	0.21	40
PDX-5403	SBS Block Copolymer	-	-	-	-	>10,000	0.30	0.50	20
PDX-5188	SBS Block Copolymer	-	-	15	-	>10,000	0.23	0.43	20

Figure 16

ABRASION RESISTANCE OF GLASS REINFORCED THERMOPLASTIC ELASTOMERS

LNP Product Code	Base Resin	Glass Fiber Content (wt %)	Taber Abrasion CS-17 Wheel, 1000 gr mg/1000 cycles
-	Olefin Rubber	-	1-2
PDX-5278	Olefin Rubber	20	28-30
-	Polyurethane	-	5-6
TF-1004	Polyurethane	20	23-25
-	Polyester Elastomer	-	4-5
YF-1004	Polyester Elastomer	20	10-11
PDX-5404	Butyl Grafted Polyethylene	-	8-9
PDX-5293	Butyl Grafted Polyethylene	20	15-16

Figure 17

EFFECT OF STRAIN RATE ON THE TENSILE PROPERTIES OF

GLASS FIBER REINFORCED THERMOPLASTIC ELASTOMERS

LNP Product Code	Base Resin	Glass Fiber Content (wt %)	Tensile Yield Strength, psi 2"/min	Ultimate Tensile Elongation, % 2"/min	Tensile Yield Strength, psi 20"/min	Ultimate Tensile Elongation, % 20"/min
-	Thermoplastic Polyurethane	0	2,000	510	3,300	320
TF-1001	Thermoplastic Polyurethane	5	3,400	270	4,000	160
TF-1004	Thermoplastic Polyurethane	20	6,800	30	8,000	25
-	Polyester Elastomer	0	2,100	500	2,300	440
YF-1001	Polyester Elastomer	5	3,500	300	3,800	100
YF-1004	Polyester Elastomer	20	7,100	12	7,600	9
-	SBS Block Copolymers	0	650	1,000	680	1,000
PDX-5230	SBS Block Copolymers	5	600	850	680	880
PDX-5231	SBS Block Copolymers	20	500	700	580	775

Figure 18

EFFECT OF STRAIN RATE ON TENSILE PROPERTIES OF GLASS FIBER REINFORCED OLEFIN RUBBER

LNP Product Code	Base Resin Modulus, psi	Glass Fiber Content (wt %)	Tensile Yield Strength, psi 2"/min	Ultimate Tensile Elongation, % 2"/min	Tensile Yield Strength, psi 20"/min	Ultimate Tensile Elongation, % 20"/min
Olefin Rubber	25,000	0	1,450	175	1,650	135
PDX-5277	25,000	5	1,450	90	1,700	85
PDX-5278	25,000	20	1,500	50	1,700	45
Olefin Rubber	55,000	0	2,400	70	2,800	50
PDX-5228*	55,000	5	2,450	40	2,800	25
PDX-5229*	55,000	20	2,800	20	2,800	15

*High modulus

Figure 19

EFFECT OF ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF GLASS REINFORCED THERMOPLASTIC ELASTOMERS

LNP Product Code	Base Resin	Glass Fiber Content (wt %)	Tensile Yield Strength @ 75°F, psi 2"/min	Tensile Yield Strength @ 140°F, psi 2"/min
-	Olefin Rubber	0	1,450	750
PDX-5277	Olefin Rubber	5	1,450	800
PDX-5278	Olefin Rubber	20	1,500	900
-	Polyurethane	0	2,000	1,200
TF-1001	Polyurethane	5	3,400	1,300
TF-1004	Polyurethane	20	6,800	1,600
-	Polyester Elastomer	0	2,100	1,500
YF-1001	Polyester Elastomer	5	3,500	3,000
YF-1004	Polyester Elastomer	20	7,100	6,600

Figure 20

CREEP RESISTANCE OF GLASS REINFORCED POLYESTER ELASTOMER @ 75°F

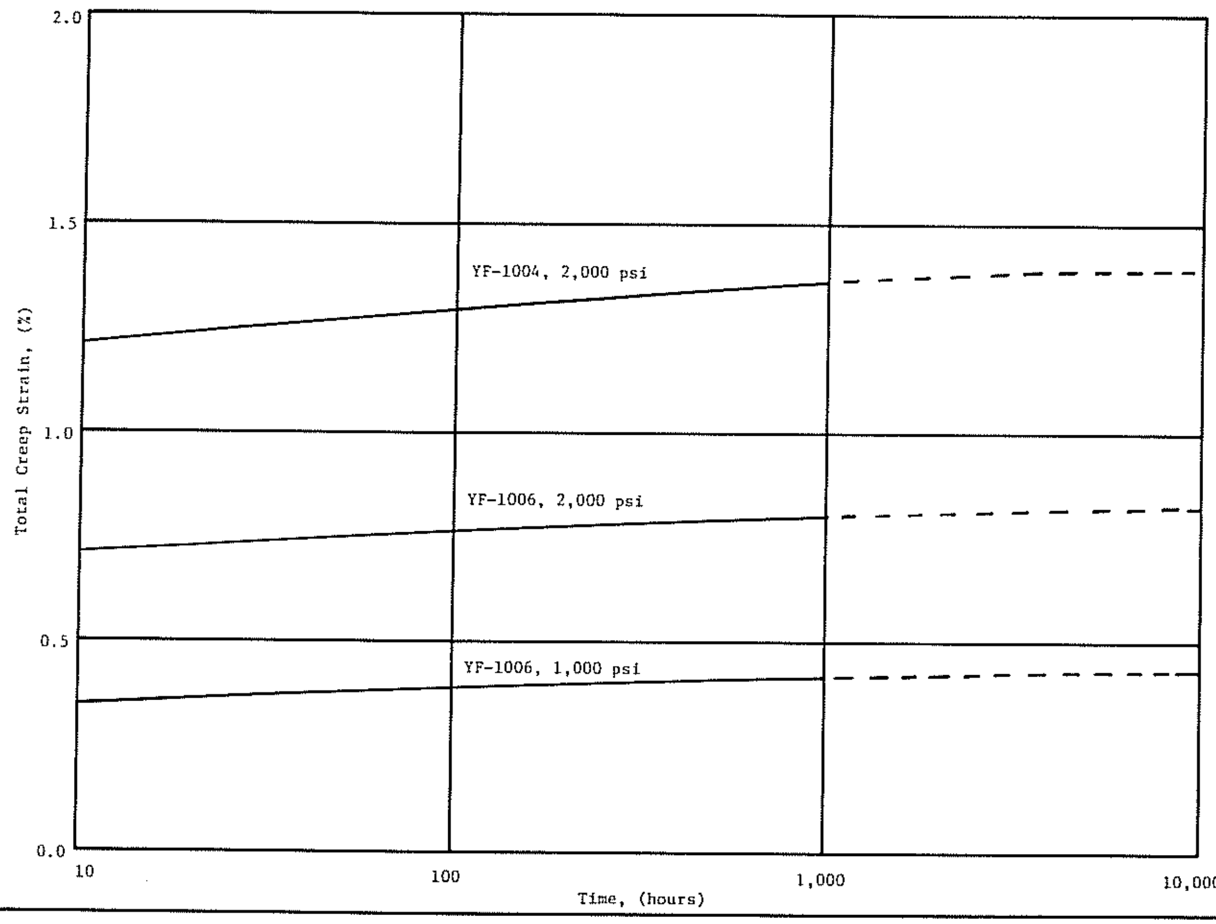

Figure 21

CREEP RESISTANCE OF GLASS REINFORCED POLYURETHANE @ 75°F