DESIGN & APPLICATION GUIDE
Cast & Molded Components of Polyurethane Elastomers

GALLAGHER

PRECISION POLYURETHANE MOLDING

YOUR TOUGHEST DEMANDS - DELIVERED.

Polyurethane Technical Data & Design Guide

Welcome to the Polyurethane Technical Data & Design Guide from Gallagher Corporation – a reference you can turn to for a general understanding of polyurethane properties, processing, problem solving and more.

Table of Contents:

Our Complete Polyurethane Molding Offer

Working three shifts at our ISO-certified, 100,000-square-foot facility, the people of Gallagher process up to 40 different cast urethane compounds every day, molded into hundreds of different tough urethane products. But there's a lot more than polyurethane processing going on.

OEMs count on our help with everything from material selection to part design to secondary operations – comprehensive expertise that helps solve even the most challenging manufacturing puzzles involving polyurethane.

Explore our complete offer

Molding Processes

Creating parts from 1/10 ounce to 2,000 pounds (a few grams to 1,000 kg) from a wide range of cast polyurethanes as well as injection molded thermoplastic urethanes and other elastomers.

Engineering

Solving complex problems by applying over 50 years of experience and insights in feasibility, design and material selection to your challenging application.

Moldmaking

Designing and building precise production molds in house to save time and make sure your part meets your needs right from the start.

Secondary Machining Processes

Cost-effective capabilities including milling, turning, grinding, die cutting and water jet cutting from one convenient, reliable source.

A Message from Rick Gallagher, President & CEO

I want your experience in working with Gallagher Corporation to be the best business experience you have had. We have optimized every aspect of our processes to deliver a successful application of one of our molded components.

Five Reasons You Can Count on Us

If you are thinking about us as a potential supplier, please keep the following in mind:

1. We have decades of application engineering experience.
2. We are financially sound, with no debt.
3. We have the capacity and staff to take on your additional business.
4. We are a progressive manufacturer with plans to stay in business a very long time.
5. We are unequivocally serious about meeting our commitments to our customers.

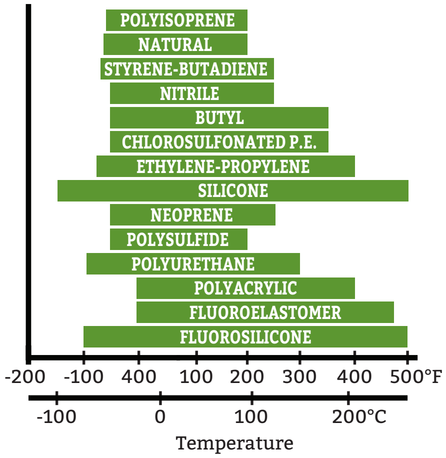
Rick Gallagher, President and CEO

Disclaimer: The information presented this document is provided as reference material only. It is not specific engineering advice related to your particular requirements. Contact Gallagher or review the data with your own engineer to confirm applicability.

Section 1: Polyurethane 101

Introduction to Urethane Elastomers

USEFUL TEMPERATURE RANGE OF COMMERCIAL ELASTOMERS



Polyurethane (or "urethane") elastomers are one type of a large family of elastic polymers called rubber. There are 14 types in general use. All of them have been commercially successful, but they are all different in several ways. The charts on these first two pages provide a quick, initial screening.

Thirteen of these elastic polymers or elastomers are called conventional rubber. That means, because they are solids, they are mixed, milled, and molded by techniques which have been in use by the rubber industry for the past 80 years. Polyurethanes are liquids and be cast in low pressure molds.

Polyurethanes Should Not Be Confused with Plastics

It is incorrect to refer to thermoset polyurethanes as plastic. Polyurethanes by definition are rubber – we do process some thermoplastic urethanes by techniques used for plastics.

The general characteristics of rubber and thermoset polyurethane are:

- Can be highly deformed without breaking
- Ability to recover rapidly and repeatedly from deformation
- Deformation is large in proportion to the original dimensions
- Large deformations produced at relatively low stress levels
- Desired stress-strain properties can often be obtained by compounding
- Stress-strain characteristics are non-linear, thus the material becomes stiffer with greater deflection and velocity of impact
- Affected by the environment and conditions under which they are employed

SELECTION GUIDE TO ELASTOMERS WHICH GENERALLY QUALIFY FOR USE FROM -40°F TO 160°F (-40°C TO 71°C) BASED ON ENVIRONMENTAL AND MECHANICAL PROPERTIES

CAPABILITIES →

RESILIENT ELASTIC MEMORY	RESILIENT ELASTIC MEMORY OIL AND GREASE RESISTANT	RESILIENT ELASTIC MEMORY OIL AND GREASE RESISTANT WEATHER, OZONE, AGE RESISTANT	RESILIENT ELASTIC MEMORY OIL AND GREASE RESISTANT WEATHER, OZONE, AGE RESISTANT ABRASION RESISTANT	RESILIENT ELASTIC MEMORY OIL AND GREASE RESISTANT WEATHER, OZONE, AGE RESISTANT ABRASION RESISTANT HIGH LOAD BEARING CAPACITY
NITRILE STYRENE-BUTADIENE NATURAL CHLOROSULFONATED P.E. ETHYLENE-PROPYLENE SILICONE FLUOROSILICONE FLUOROELASTOMER POLYACRYLIC NEOPRENE POLYURETHANE BUTYL POLYSULFIDE POLYISOPRENE	NITRILE CHLOROSULFONATED P.E. SILICONE FLUOROSILICONE FLUOROELASTOMER POLYACRYLIC NEOPRENE POLYURETHANE POLYSULFIDE	CHLOROSULFONATED P.E. SILICONE FLUOROSILICONE FLUOROELASTOMER POLYACRYLIC NEOPRENE POLYURETHANE POLYSULFIDE	NEOPRENE POLYURETHANE	POLYURETHANE

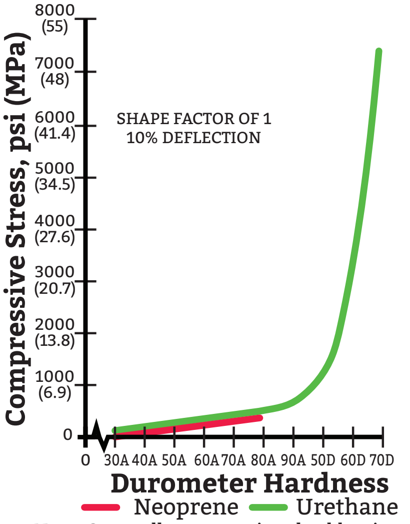
QUALIFYING ELASTOMERS →

Like All Engineered Materials, Polyurethane Has Limits

1. Typically, polyurethane rubber should not be used in dynamic applications above 200°F (93°C). When tested at 200°F (93°C) their properties are generally only half of those measured at 75°F (25°C). They heat age well however, and the effect of high temperatures up to 250°F (120°C) for weeks on physical properties is almost completely reversible when tested again at 75°F (25°C). We have some polyurethanes that perform well up to 300°F (150°C).
2. In most dynamic applications we recommend staying at temperatures below 160°F (70°C). The normal, high property working range is -40°F to 160°F (-40°C to 70°C). At 160°F (70°C) the properties of the elastomer begin to show a decline. The bond between urethane and metal weakens considerably above 160°F (70°C).
3. Generally, polyurethanes exhibit high hysteresis and low thermal conductivity. They do not dissipate heat built up by dynamic action quickly. Avoiding heat build-up in an elastomeric part is a paramount consideration in design. In practice, this is usually done by controlling the amplitude of the deflection. For instance, using urethane elements in series allow large deflections.

4. Long term exposure to hot, humid environments should be avoided. Some urethanes are much more resistant than others to this environment. We can help you select the correct type.
5. Certain chemicals such as concentrated acids and solvents attack polyurethanes, and polyurethanes should not be put into continuous service in these environments. Refer to the Oil and Chemical Resistance tables.

LOAD BEARING CAPACITY NEOPRENE VS. POLYURETHANE



Note: Generally, conventional rubber is unsatisfactory above a compressive stress of 500 psi (3.4 Mpa)

The Distinction of Polyurethane Rubber

Polyurethane raw materials are liquid, which permits them to be pumped, metered, mixed and dispensed by machines under very precise control of temperature and ingredient proportions. They enter molds as a liquid at low pressure and are "cured" at the same elevated temperature as that which they are mixed. This unique characteristic allows us to mold very large urethane parts with thick cross-sections that are completely uniform throughout.

HOW TO USE THIS CHART

1. List the primary properties needed.
2. Delete elastomers with a *U* in a required property.
3. The elastomers remaining on your list – *G* or *E* – should be the viable candidates to investigate.

	IIR	CSM	EP	FKM	FMQ	NR	CR	NBR	ACM	AU	EU	IR	T	SI	SBR
Resilience	G	G	G	G	G	E	E	G	G	G	E	E	G	G	G
Load Bearing Capacity	G	G	G	G	U	G	G	G	G	E	E	G	U	U	G
Compression Set	G	G	G	E	E	G	G	G	G	G	G	G	G	E	G
Impact Resistance	G	G	G	U	U	E	G	G	U	E	E	E	U	U	E
Abrasion Resistance	G	E	G	G	U	E	E	E	G	E	G	E	U	U	E
Tear Resistance	G	E	G	U	U	E	G	G	G	E	G	E	U	U	G
Cut Growth Resistance	G	E	G	U	U	E	G	G	G	E	G	E	U	U	G
Weather Resistance	E	E	E	E	E	G	E	G	E	G	E	G	E	E	G
Oxidation Resistance	E	E	E	E	E	G	G	G	E	G	E	G	E	E	G
Grease, Oil Resistance	U	E	U	E	G	U	E	E	G	E	G	U	G	G	U
Temperature Range	-50°F to 350°F	-50°F to 350°F	-40°F to 275°F	0°F to 475°F	-75°F to 400°F	-50°F to 200°F	-50°F to 250°F	-50°F to 250°F	0°F to 400°F	-100°F to 250°F	-100°F to 250°F	-50°F to 200°F	-50°F to 200°F	-75°F to 400°F	-50°F to 250°F

Abreviation Key:

IIR	**Butyl**
CSM	**Chlorosulfonated P.E.**
EP	**Ethylene-Propylene**
FKM	**Fluoroelastomer**
FMQ	**Fluorosilicone**
NR	**Natural Rubber**
CR	**Neoprene**
NBR	**Nitrile Butadiene**
ACM	**Polyacrylate**
AU	**Polyester Urethane**
EU	**Polyether Urethane**
IR	**Polyisoprene**
T	**Polysulfide**
SI	**Silicone**
SBR	**Styrene Butadiene**

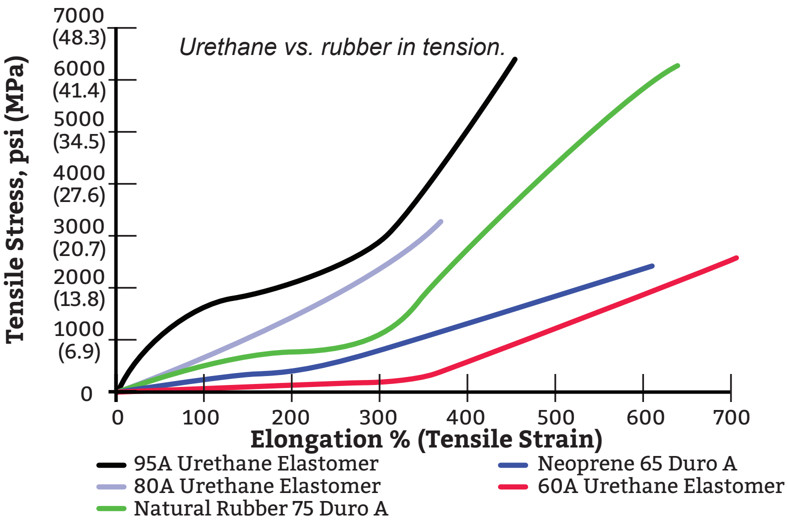
E	**Excellent**
G	**Good**
U	**Unsatisfactory**

Polyurethane Advantages vs. Metal, Plastic and Ordinary Rubber

Polyurethanes have many advantages over metals, plastics and conventional rubbers:

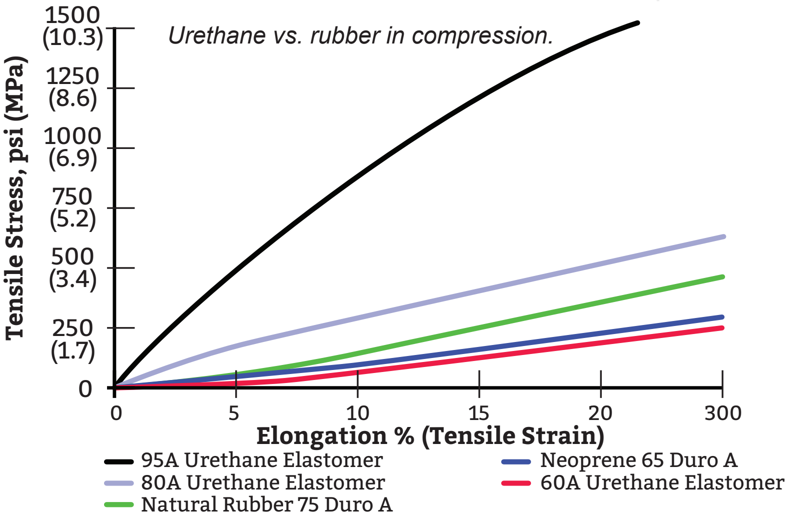
Vs. Metal	Vs. Plastics	Vs. Rubber
Lightweight	High Impact Resistance	High Abrasion Resistance
Noise Reduction	Elastic Memory	High Cut & Tear Resistance
Abrasion Resistance	Abrasion Resistance	Superior Load Bearing Capacity
Corrosion Resistance	Noise Reduction	Thick Section Molding Without a Cure Gradient
Resilience	Variable Coefficient of Friction	Colorability
Impact Resistance	Resilience	Oil Resistance
Flexibility	Thick Section Molding	Ozone Resistance
Easily Moldable	Lower Cost Tooling	Radiation Resistance
Non-Conductive	Lower Temperature Resistance	Broader Hardness Range
Non-Sparking	Resistance to Cold Flow (or Compression Set)	Castable Nature
Often Lower Cost	Radiation Resistance	Lower Cost, Low Pressure Tooling

Urethane vs. Rubber: A Closer Look



In Tension

Seldom do we use urethane elastomers in tension and then only to a small fraction of their ultimate strength. Tensile stress strain curves for several compounds are shown merely as information in the following graphs:



In Torsion

Only a small percent of urethane applications are being used in torsion. However, there are a few outstanding examples and we would be pleased to work with you on this.

More than 90% of our applications for urethanes use the extraordinary stress-strain relationship of urethanes in compression..

Section 2: Key Polyurethane Properties

Load-Bearing Capacity

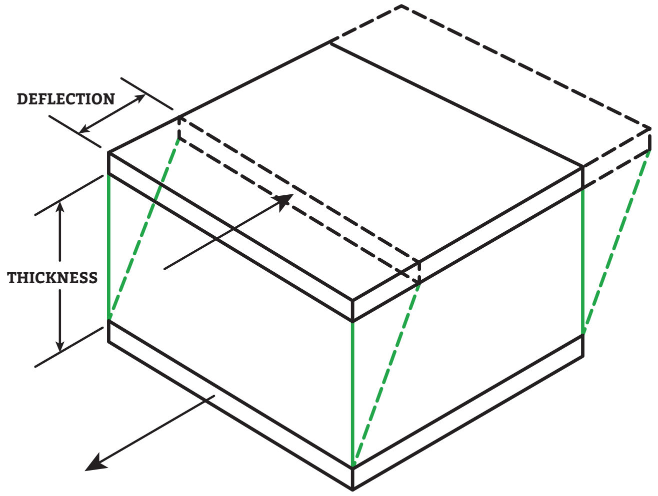
The urethanes have an unusually high load-bearing capacity relative to all other elastomers. They have deflection and recovery capabilities possessed by no other plastic or metal.

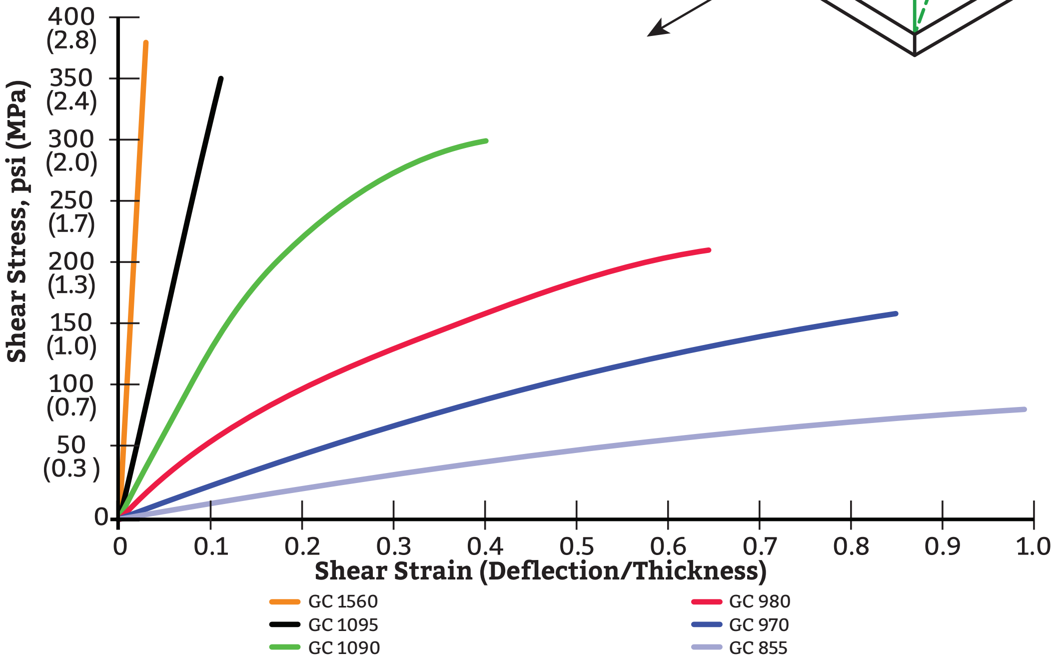
This is the most common application for the high-load and impact-resistant urethanes. We'll attempt to provide a considerable amount of information within the constraints of this Guide. There is much more information available, however – just contact us with your questions.

Urethanes in Shear

Elastomers in shear are generally used in mounting and suspension applications. Urethane elastomers deflect more easily in shear than in compression. Shear is essentially a combination of tensile and compressive forces acting at right angles to each other.

In every application that would use the high shear strength of urethanes, the weakness is the dependence on a good bond between the urethane and metal. There are specific ways Gallagher has successfully overcome this weakness. Contact us to learn more.





Urethane Fatigue Considerations

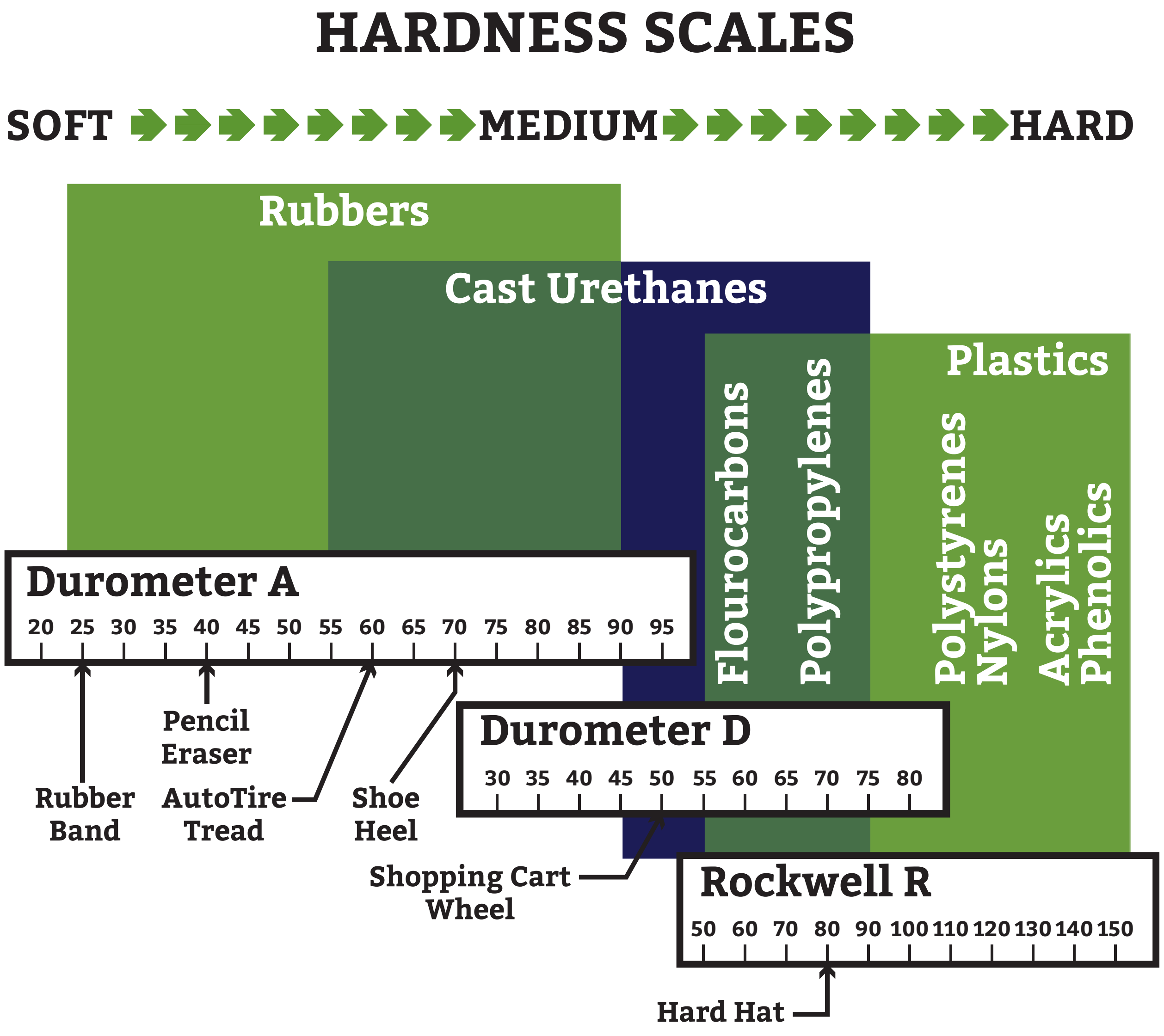
Fatigue is an important consideration in the design of parts for cyclic dynamic applications. Fatigue and cut growth resulting from cyclic stress-strain are related. When testing for fatigue resistance for a specific application, it's important to test at a strain energy experienced by the part in actual service.

Strain energy is a function of both the modulus of the material and the strain cycle the material sees. Also important with polyurethanes is to test at various levels of stoichiometry (polymer to curative ratio) because we have seen dramatic improvements in flex fatigue resistance by this chemical adjustment.

This is another reason why teamwork between the design engineer, the product engineer and our chemists is so important to problem solving.

Polyurethane Hardness

The hardness of urethanes can easily be measured with an inexpensive instrument called a durometer. However, hardness is not a good indicator of performance. It cannot be relied upon as a specification by itself. First, let's discuss the commonly used hardness scales. We will then proceed to show you that hardness is not a sufficient indicator of quality or performance.



Hardness Scales. Note: the durometer "A" scale is used for the softer urethanes. The durometer "D" scale is used for the harder urethane compounds (above 95 A durometer)

Why Hardness Measurement Alone Is a Poor Quality Indicator

The principal urethane systems we work with day-to-day are derived from eight basic chemical structures. They are:

- TDI POLYETHER/POLYOL
- TDI POLYESTER/POLYOL
- TDI POLYESTER/DIAMINE
- PPDI POLYESTER/POLYOL
- TDI POLYETHER/DIAMINE
- MDI POLYETHER/POLYOL
- MDI POLYESTER/POLYOL
- PPDI POLYETHER/POLYOL

Compounds of the Same Hardness Are Not Necessarily the Same

The urethane systems above can make compounds in the same hardness range, but with drastically different physical and engineering properties. That's why we stress that hardness alone is not an adequate specification for any rubber, but particularly for urethanes.

Observe the difference between a TDI Polyether System and an MDI Polyester at the same hardness:

Polyurethane Advantages vs. Metal, Plastic and Ordinary Rubber

Polyurethanes have many advantages over metals, plastics and conventional rubbers:

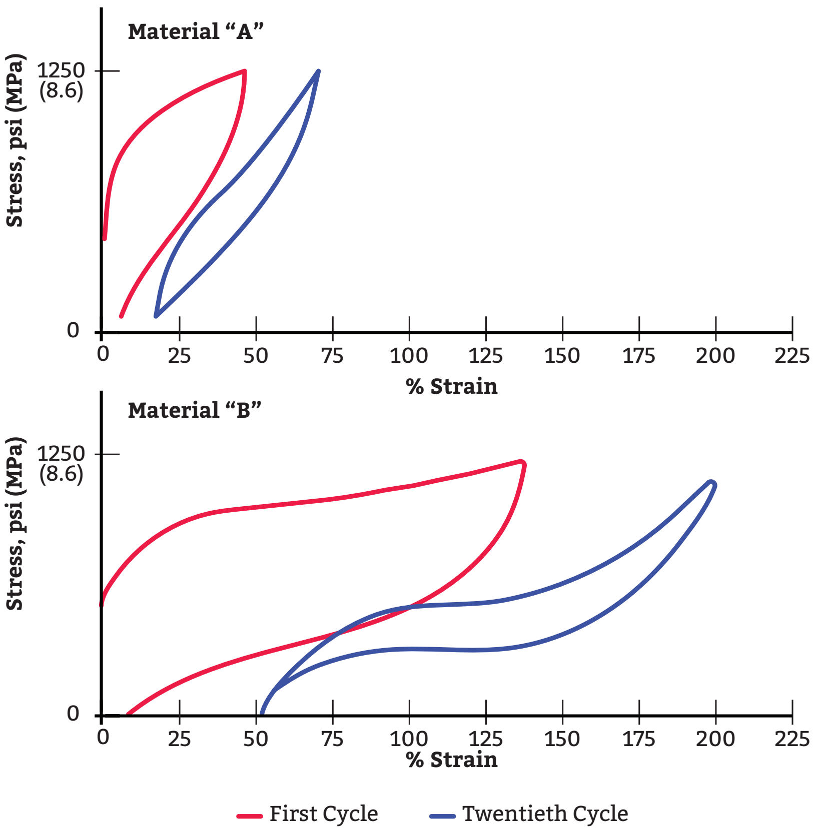
BOTH MATERIALS ARE THE SAME HARDNESS, Durometer A 95	TDI POLYETHER (Material A)	MDI POLYESTER (Material B)
100% Modulus, psi (MPa)	1,800 (12.4)	1,570 (10.8)
300% Modulus, psi (MPa)	3,400 (23.4)	3,180 (21.4)
Tensile Strength, psi (MPa)	5,000 (34.5)	6,460 (44.5)
Elongation Break, %	400	440
Die C Tear Strength, pli (kN/m)	500 (87.7)	762 (134.0)
D-470 Split Tear Strength, pli (kN/m)	150 (26.3)	175 (30.7)

It's obvious from the data that the two elastomers are not the same, even though the hardness is the same. We have ways to identify (with spectrographic and chemical analysis) the structure of elastomers at the same hardness, but the process is costly and time consuming. Actually, they are both excellent materials but with widely different engineering properties. One will perform better in some applications and the other will perform well in different applications.

The data in the above table was produced in laboratory tensile tests. For most industrial applications, we need to know how they behave in dynamic situations and how they will endure the application's environment. Very few urethane applications would require a part to be strained in tension greater than 100%. Most applications operate in the range of 0 – 30%. The table above shows only the first strain cycle; this is because the samples are taken to failure in that first cycle. The cycled stress-strain test (to the right) shows the big difference between the two compounds (95A TDI PTMEG Polyether vs. 95A MDI Polyester). After 4 - 5 strain cycles, equilibrium is achieved and performance is reproducible. The different behavior tells us that an application as a shock mount or die spring would benefit from the consistent spring rate and ability to handle reasonable loads of the TDI-Polyether (Material A).

On the other hand, a chain sprocket with relatively low loads might benefit from the more forgiving flexibility of the MDI Polyester (Material B) if there was a mismatch of mating surfaces.:

STRESS-STRAIN CYCLING OF TWO DIFFERENT 95A DUROMETER URETHANES



Urethane Bonded To Metal

Urethane can be attached permanently to metals and composites very readily during the molding or casting process. Bond strength exceeding the tear strength of urethane can be achieved.

The bonding process requires that the substrate must be chemically clean and free of all contamination. Cured urethane may also be adhered to metal and composites, though the bond strength is not as high as that achieved during the molding process. We can provide instructions for adhering cured urethane to other materials.

Oil and Chemical Resistance of Polyurethanes

Here are partial lists of oil and chemical media to which Gallagher Corporation polyurethanes have been subjected. This data was obtained on small billets totally immersed. Always test specific compounds under your particular field conditions.

Note: Unless otherwise stated, all immersion test data was generated at room temperature. Elevated temperatures usually increase the fluid's effect on the urethane. If you have a specification not listed, contact us. We have more test results on file.

KEY:

A = No or Little Effect B = Moderate Effect C = Probably Unsatisfactory D = Unsatisfactory

FLUID ASTM D-471 (158°F/70°C)	RATING	FLUID ASTM D-471 (158°F/70°C)	RATING
NUMBER 1 OIL	A	NUMBER 2 OIL	B
NUMBER 3 OIL	B		

SPECIFICATION FLUID	RATING	SPECIFICATION FLUID	RATING
MIL-H-13862	B	MIL-H-13866A	B
MIL-H-13910B	C	MIL-H-13919A	B
MIL-H-15017	A	MIL-H-15018B	A
MIL-H-15719A	D	MIL-H-15019C	A
MIL-H-16958A	B	MIL-H-17331D	A
MIL-H-17353A	B	MIL-H-18486A	A
MIL-H-19701	C	MIL-H-21260	A
MIL-H-22396	A	MIL-H-23699A	C
MIL-H-25336B	C	MIL-H-26087A	A
MIL-H-27694A	A	MIL-H-3150A	A

Oil and Chemical Resistance of Polyurethanes (continued)

KEY:

A = No or Little Effect   B = Moderate Effect   C = Probably Unsatisfactory   D = Unsatisfactory

FLUID	RATING	FLUID	RATING	FLUID	RATING
ACETIC ACID, 30%	C	ACETONE	D	AMMONIUM HYDROXIDE	B
AMMONIUM NITRATE	D	ANIMAL FATS	A	ASPHALT	B
ASTM REF. FUEL NO. 1 (BELOW 158°F)	A	ASTM OIL NO. 3 (BELOW 158°F)	B	ASTM REF. FUEL A	A
ASTM REF. FUEL B	B	ASTM REF. FUEL C	C	BARIUM CHLORIDE	A
BARIUM SULFATE	A	BARIUM SULFIDE	A	BORIC ACID	A
BUTANE	A	BUTTER	A	BUNKER OIL	B
CALCIUM CHLORIDE	A	CALCIUM HYDROXIDE	A	CALCIUM NITRATE	A
CARBON DIOXIDE	A	CARBON MONOXIDE	A	CHLORINE WET, DRY, OR GAS	D
CITRIC ACID	B	COCONUT OIL	A	COD LIVER OIL	A
COPPER CHLORIDE	A	COPPER CYANIDE	A	COPPER SULFATE	A
CORN OIL	A	COTTON SEED OIL	A	CYCLO HEXANE	B
DIESEL OIL	B	DI ETHYL ETHER	A	DOWTHERM OIL	B
ETHYL ALCOHOL	C	ETHYL CELLULOSE	B	ETHYL CHLORIDE	C
ETHYL ETHER	B	ETHYLENE GLYCOL	C	GASOLINE (WITH ALCOHOL)	B
GLUCOSE	A	GLYCERINE	A	GLYCOLS	C
HYDRAULIC OIL (PETROLEUM BASED)	A	HYDRAULIC FLUIDS (SYNTHETIC)	D	HYDROGEN GAS	A
ISOOCTANE	B	KEROSENE	B	LARD	A
LINSEED OIL	B	LIQUIFIED PETROLEUM GAS	B	LYE	A,B
MAGNESIUM CHLORIDE	A	METHANE	B	METHYL ALCOHOL	D
METHYLENE CHLORIDE	D	MINERAL OIL	A	NATURAL GAS	B
NITRIC ACID - CONC.	D	NITRIC ACID - DILUTED	C	NITROGEN	A
OLEUM SPIRITS	B	OLIVE OIL	A	OXYGEN - 200°F	A
PEANUT OIL	A	PETROLEUM BELOW 160°F	A	PETROLEUM BELOW 250°F	B
PETROLEUM ABOVE 250°F	D	PHOSPHORIC ACID 20%	B	PHOSPHORIC ACID 45%	C
POTASSIUM CHLORIDE	A	POTASSIUM HYDROXIDE	A	POTASSIUM NITRATE	A
POTASSIUM SULFATE	A	PROPANE	B	RADIATION	A
SEWAGE	A	SILICATE ESTERS	A	SILICONE GREASES	A
SILICONE OILS	A	SOAP SOLUTIONS	B	SODIUM CHLORIDE	B
SODIUM HYDROXIDE	B	SODIUM PEROXIDE	A	SODIUM PHOSPHATE	A
SODIUM SULFATE	B	SOYBEAN OIL	B	STEARIC ACID	A
SULFURIC ACID - DILUTED	C	SULFURIC ACID - CONC.	D	TANNIC ACID	A
TOLUENE	D	TRANSMISSION FLUID TYPE A	A	TUNG OIL	B
WATER, FRESH	A	WATER, SALT	A	WHISKEY, WINES	A

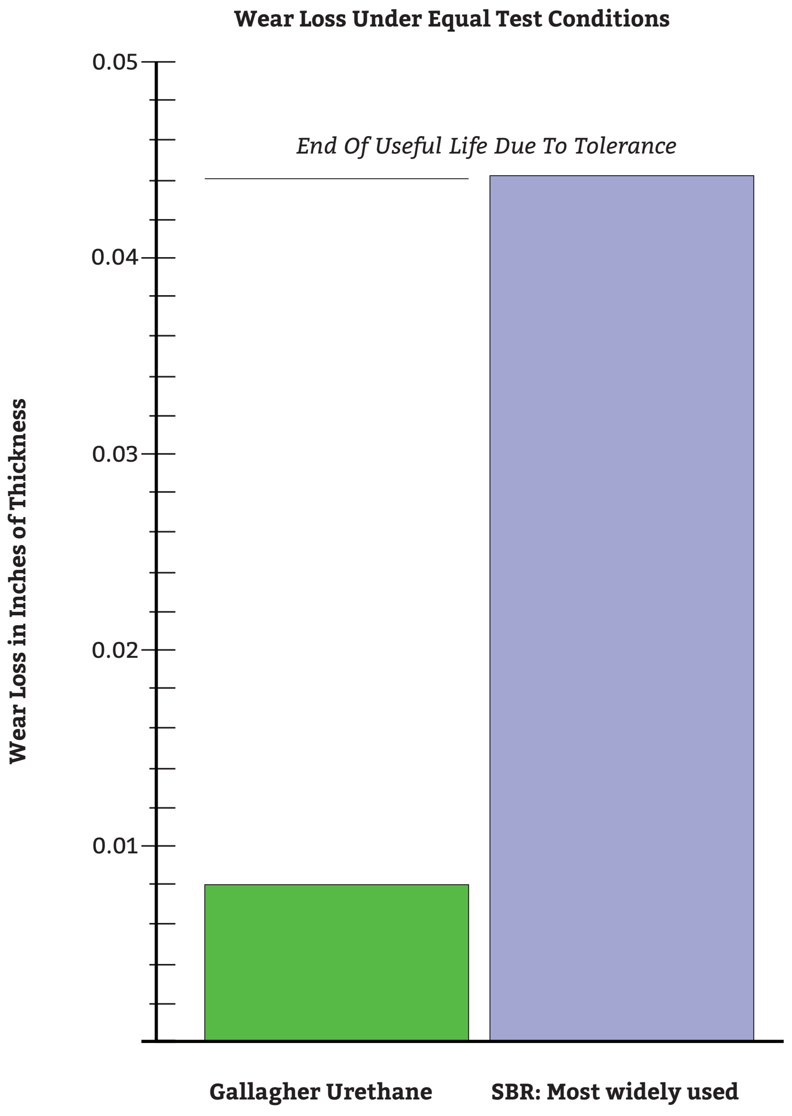
Polyurethane Abrasion Resistance

Unquestionably, the urethanes have outstanding abrasion resistance. They outwear metals, plastics, and other rubbers by a wide margin, often by 8 to 1 or more.

Abrasion is caused by many actions, such as impingement, erosion, impact, scuffing, and sliding. Add to that the many variables which affect the abrasion rate such as pressure, temperature, velocity and lubricity.

It's obvious, then, that abrasion is very application specific. There are a few standard tests such as the National Bureau of Standards (NBS), DIN and the Taber Abrasion that provide guidance, but specific tests often have to be designed to closely approximate the intended service. Here are some empirical conclusions we have formed over the years of following field tests:

- Soft, resilient compounds – 60A to 85A – last longest in particle impingement types of service.
- Medium durometer, resilient compounds – 85A to 95A – last longest in abrasive slurry (e.g. pump impellers, etc.).
- 90A to 95A durometer compounds work best in impact and sliding types of abrasion found in sand, gravel, coal and ore mining applications.
- The very hard compounds – 65D to 75D durometer – work best in bushing and bearing applications – in wet or dry environments – often where sand, grit or mud are present.



There is no substitute for a field test of 2 or 3 chosen compounds. With our experience and knowing your field performance, we can help you select test candidates

Case Study: Polyurethane Abrasion Testing Results

Perform laboratory testing to determine if certain Gallagher Corporation polyurethane compounds are more abrasion resistant.

ASTM G65: Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus Procedure A

Abrasion Test Machine	**Falex ATM S/N AT-88-019**
RPM:	**200**
Force:	**30 lbf**
Revolutions	**6,000**
Wheel Diameter:	**9"**
Wheel Material:	**Chlorobutyl Rubber**
Specimen Dimensions:	**1/2" × 1" × 3"**
Aggregate:	**Rounded Quartz (AFS 50/70)**

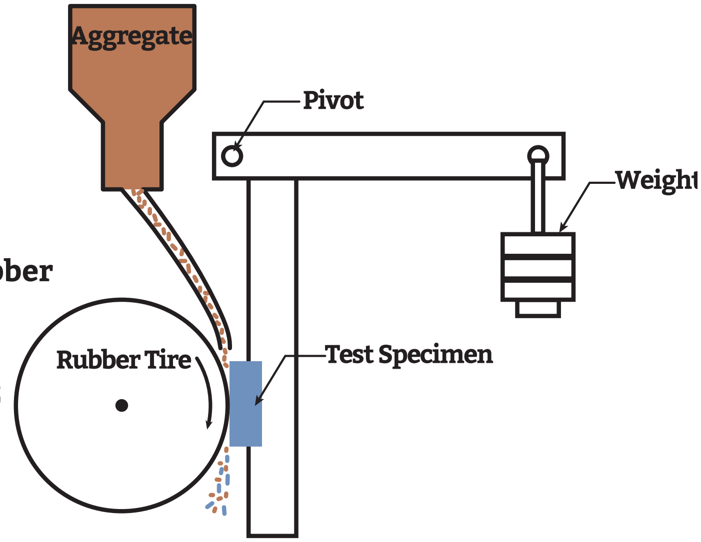


Figure 1: Testing Apparatus and Specifications

Test Description:

Laboratory test procedure ASTM G65 was chosen for this experiment, it was performed by an independent testing facility experienced in this field. Per the ASTM testing procedure this test is used to, “rank materials in their resistance to scratching abrasion under a specified set of conditions. Test results are reported as volume loss in cubic millimeters, per the ASTM standard. An illustration detailing the testing apparatus and equipment specifications are shown in Figure 1. This test was conducted using Procedure A of ASTM G65. Test specimens were carefully weighed before and immediately following the test procedure. Mass loss was converted to volume loss using the density of each material.

Test Results:

Three polyurethane compounds, UHMW and D2 Tool Steel hardened to HRc 58.5-60.5 were samples selected for this experiment. GC1560 is a widely used general purpose polyether polyurethane compound. Test results are provided in Figure 2, abrasion resistance for UHMW was used as the benchmark for comparing the different polyurethane compounds. Of all the samples included in this test, GC995 produced the most favorable results and also out-performed the benchmark, UHMW.

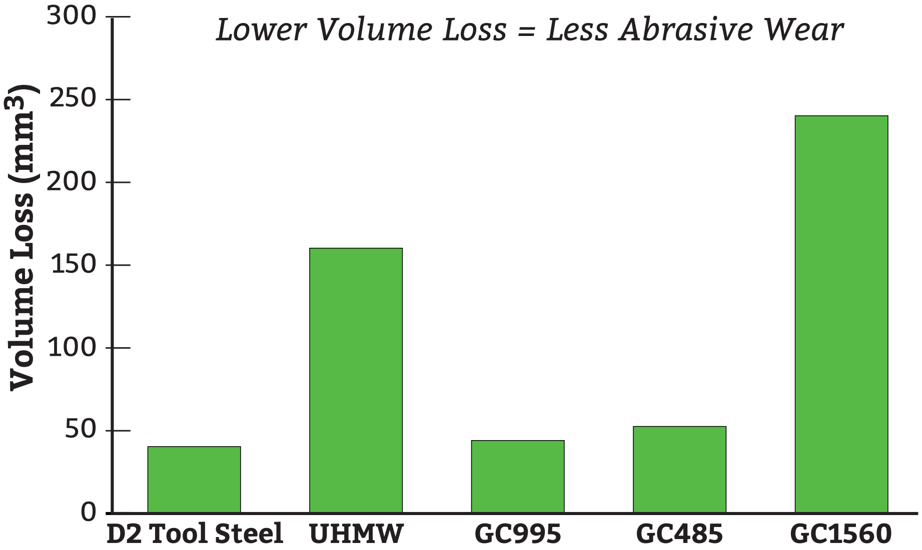
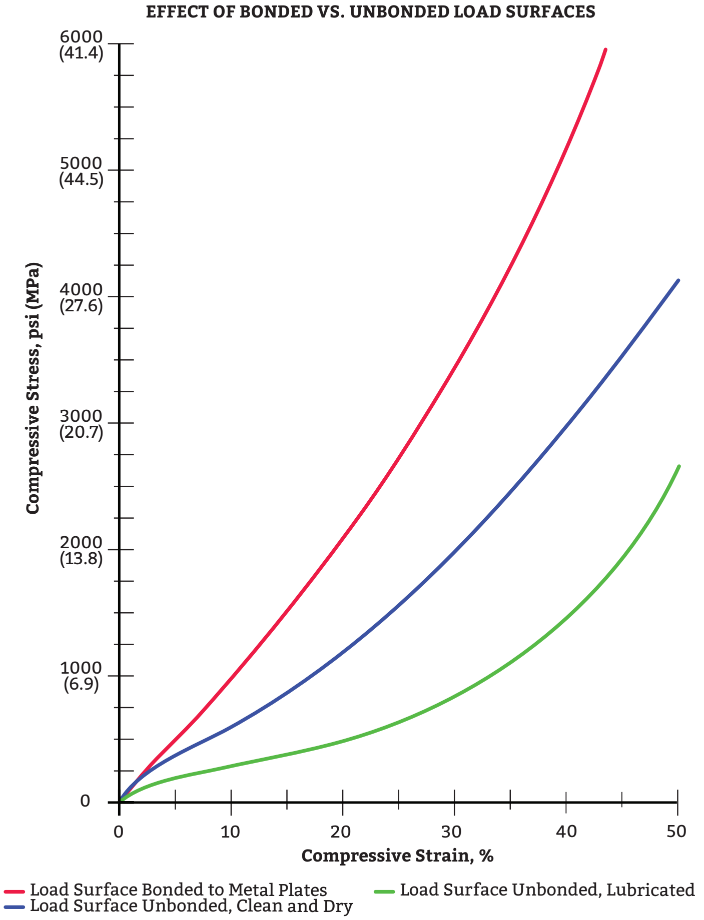


Figure 2: Abrasion Test Results

Section 3: Design Considerations & Calculations

Effect of Loading Conditions on Polyurethane

Given an elastomeric shape (where the top and bottom surfaces are flat and parallel) which is compressed between parallel platens, the loaded surfaces of the elastomer want to spread or slip laterally, thus increasing the effective load-bearing area. If, on the other hand, the loaded surfaces in contact with the platens are restricted from lateral movement, the compression-deflection behavior of the piece will be different than if the surface is free to spread laterally.



Effect of bonded vs. unbonded load surfaces on same compound and same shape factor.

Shape Factor

The compression-deflection relationship is modified by the shape of the part. Shape has only a minor effect in tension and shear.

For example, consider two blocks of urethane. One is a cylinder, the other is a block of the same height and the same cross-sectional area but is rectangular rather than circular. Both blocks are made from the same compound and the top and bottom surfaces are bonded to metal. If the same weight is placed on each block, the deflection will be greater for the rectangular block than for the cylindrical block. Neither block loses perceptible volume during deflection; they bulge at the sides that were perpendicular to the top and bottom surfaces. The area under the load is the same for each block, but the area of the side walls (the total area free to bulge) on the rectangular block is greater than the side wall area of the cylinder – thus increasing the area free to bulge, making bulging easier and permitting greater vertical displacement.

The influence of shape is substantial and can be expressed numerically as shape factor (SF). Shape factor is the ratio of one loaded surface area to the total area free to bulge. Parts of the same compound and shape factor behave almost identically in compression, regardless of the actual shape, provided the pieces have parallel loading faces, whose thickness is not more than two times the smallest linear dimension (to prevent buckling) and top and bottom surfaces are not free to move laterally.

How to Use Shape Factor in Design

Shape factor is a simple concept. In elastomer design for compression, it is critical. Keep in mind that elastomers behave like incompressible hydraulic fluids. Under load, they do not change volume. The following charts and series of examples show how urethane behaves under load and how you calculate the shape factor

Example 1:

Problem: Assume a urethane pad 8" square by 1" thick, made of 90A durometer (GC 1090) compound. How much will the pad deflect under a load of 128,000 pounds?

(A) The Shape Factor of the pad is:

$$SF = \frac{\text{Loaded Area}}{\text{Bulge Area}}$$

$$SF = \frac{8 \times 8}{4 \times 8 \times 1}$$

$$SF = \frac{64\ in^2}{32\ in^2} = 2$$

(B) $$\frac{128{,}000\ lbs}{64\ in^2} = 2000\ psi$$

(C) On the 90A durometer graph on the curve for a shape factor of 2.0 we note that 2,000 psi produces a 17% deflection. Therefore, the pad will deflect about 0.17" under this load.

Example 2:

Problem: What compound to choose for a 4" square pad by 2" thick to handle a 10,000 lb. load. The pad should be able to deflect 1/4".

(A) $$SF = \frac{\text{Loaded Area}}{\text{Bulge Area}}$$

$$SF = \frac{(\pi \times (6/2)^2) - (\pi \times (1.25/2)^2)}{(\pi \times 6 \times 1.5) + (\pi \times 1.25 \times 1)}$$

$$SF = \frac{27 in^2}{32.2\ in^2} = 0.8$$

(B) The highest load bearing capacity at 5% deflection is attainable with the 75D durometer compound (GC 1575).

(C) At a shape factor of 0.8 we could expect to handle about 4,500 psi compressive stress. Therefore, the pad will take approximately 121,000 pounds at a deflection of 5% or 0.075".

Example 3:

Problem: What compound to choose for a 4" square pad by 2" thick to handle a 10,000 lb. load. The pad should be able to deflect 1/4".

(A) The Shape Factor of the pad is:

$$SF = \frac{\text{Loaded Area}}{\text{Bulge Area}}$$

$$SF = \frac{4 \times 4}{4 \times 4 \times 4}$$

$$SF = \frac{16\ in^2}{32\ in^2} = 0.5$$

(B) A deflection of 13% on a 2" thick pad is 1/4"

(C) $$\frac{10{,}000\ lbs}{16\ in^2} = 625\ psi$$

(D) Checking the 0.5 shape factor curves, we see that at 13% deflection, the 95A durometer (GC 1095) compound comes closest with about 700 psi (11,000 pounds total).

Design Recommendations:
Maximum Strain for Compressive Loading

Hardness	60A	75A	80A	85A	90A	95A	60D	75D
Static Load, Long Term	15%	15%	15%	15%	10%	10%	5%	2%
Dynamic Service (0.32Hz)	25%	20%	20%	15%	15%	10%	5%	5%
Dynamic Service (0.16Hz)	35%	35%	35%	25%	25%	20%	10%	5%

These are approximations for "average" service conditions. Please check with us for specific application recommendations.

Compressive Stress-Strain Curves for Various Polyurethane Compounds

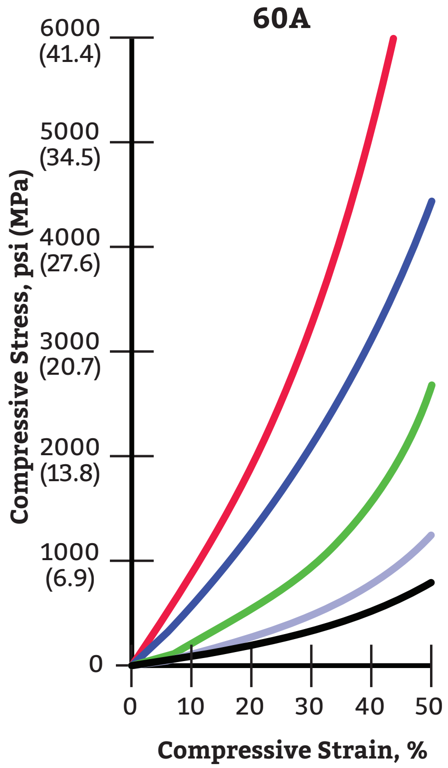
A high percentage of all urethanes are related to the unique high load bearing and impact resistance of urethanes, let's consider the load bearing ability of typical compounds.

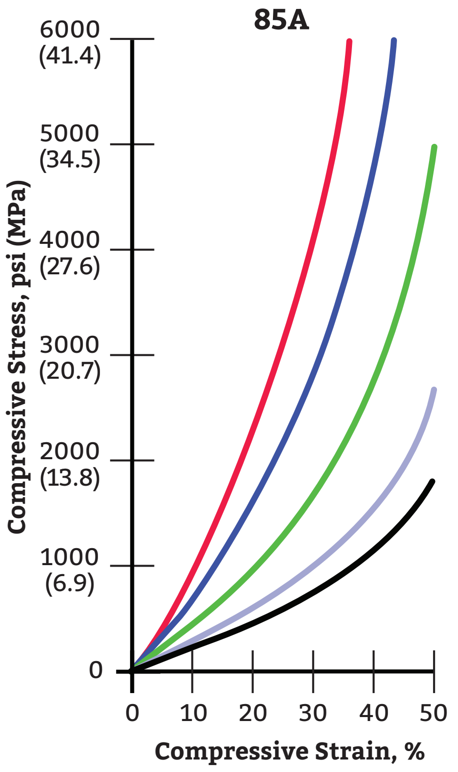
Note: This data was obtained on an Instron compression machine using specimens which were bonded top and bottom to steel plates.

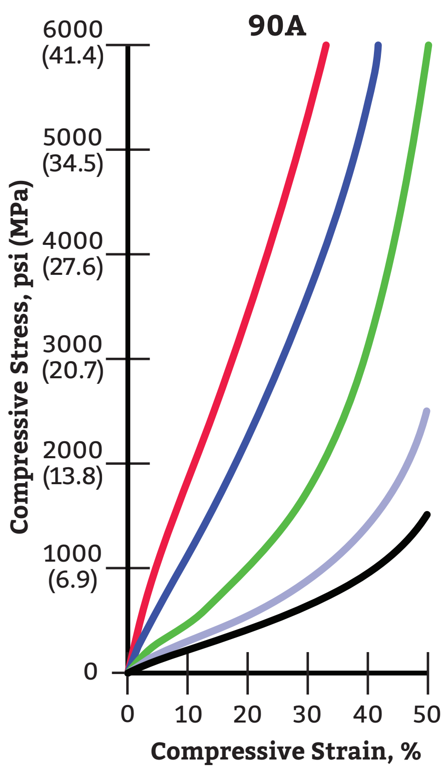
How to Use Stress-Strain Curves to Estimate Load-Bearing Capacity

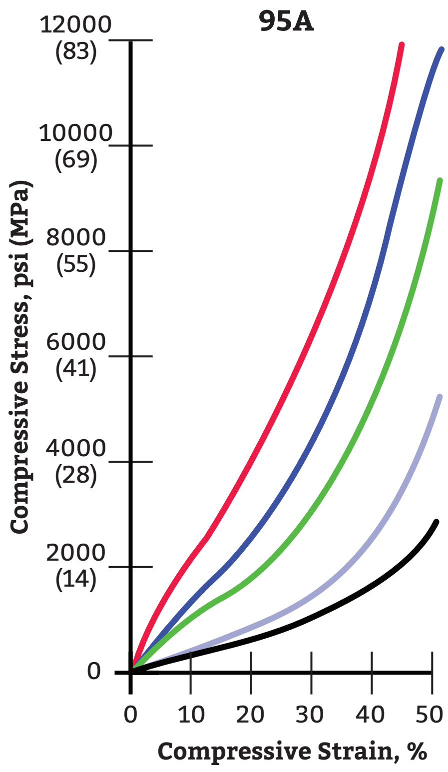
To effectively use compression-deflection data in design, the designer must know the test conditions under which the data were obtained. For uniformity, we have shown all the compression-deflection data obtained with the loaded surfaces bonded to metal. To fully use the data, it's important to understand the significance of shape factor.

The curves on the following charts were obtained using specimens whose loaded surfaces were bonded top and bottom to steel plates. In unbonded situations where lateral slippage is expected, such as in an oil or water environment, a lab test will be needed to correct the graphs. You should test a specimen with the appropriate shape factor in a simulated condition. The compression-deflection characteristic of a fabricated part may vary as much as +/- 10% from the curves shown here for a compound of that hardness.

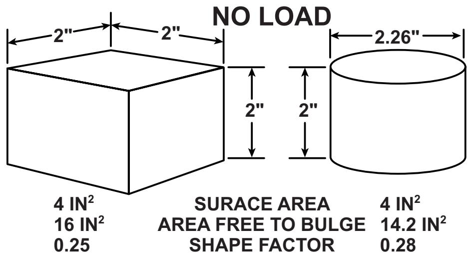


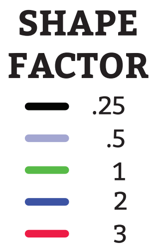




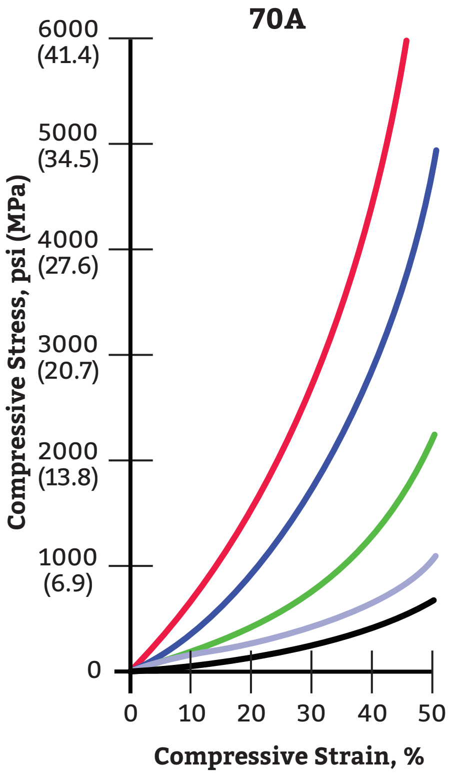


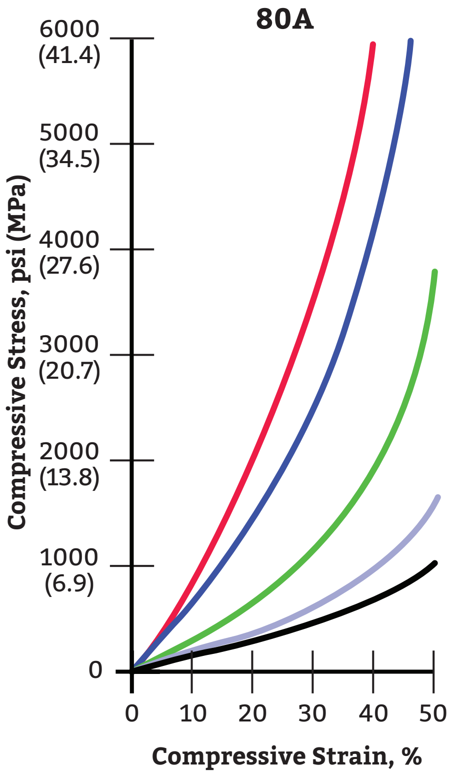
Shape Factor: Ratio of the Area of One Loaded Surface to the Total Area of Unloaded Surfaces Free to Expand

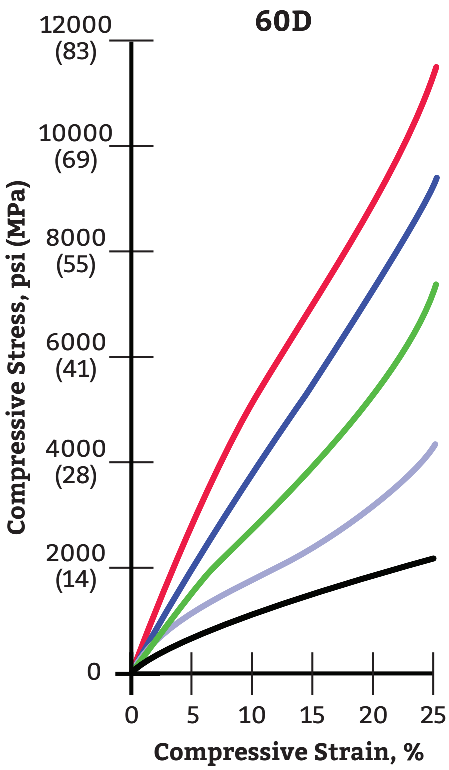




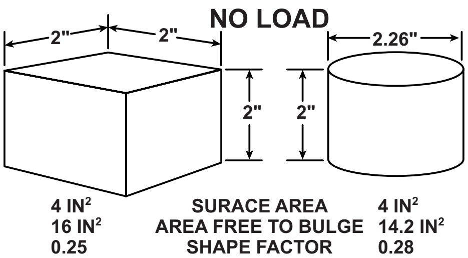
Compressive Stress-Strain Curves for Gallagher Urethane Compounds







Shape Factor: Ratio of the Area of One Loaded Surface to the Total Area of Unloaded Surfaces Free to Expand



SHAPE FACTOR

- .25
- .5
- 1
- 2
- 3

Impact Shock Force Reduction

A urethane bumper can be designed by equating the kinetic energy of a moving body to the total work the bumper does as it brings the moving body to a stop. The work done is represented by the area under the force-deflection curve.

Unlike steel springs, the dynamic spring rates of various urethanes can range from 1.25 to 2.5 times greater than their static spring rates, depending on the compound. Also unlike steel springs, a significant percentage of the input energy is converted to heat. By controlling the deflection per cycle we can control the heat buildup due to hysteresis so the urethane is not overheated.

Fortunately, we can simplify the analysis in some applications. Even though urethanes behave in a nonlinear way, we can treat them as linear materials in deflections up to about 15-20%. This allows us to approximate the strain energy, the area under the load deflection curve, as the area of a triangle with one leg being the reaction force at maximum deflection and the other leg the maximum deflection.

Example:

An 800 pound (362.kg) transfer carrier travels at 10 ft/sec and hits a stop once per minute. Without a bumper to decelerate the carrier, the impact force may exceed a million pounds. To protect the machine we should limit the impact or transmitted force to 50,000 pounds by installing a urethane bumper. Due to limited space the bumper will be 6 inches in diameter by 3 inches long (15cm x 7.6cm), bonded between metal plates. Let's select the right urethane.

The Kinetic Energy of the carrier is:

$$KE = \frac{1}{2} mv^2$$

$$KE = \frac{1}{2} \left(\frac{800 \text{ lbs}}{32.2 \text{ ft/s}^2} \right) \times \left(10 \text{ ft/s} \right)^2$$

$$KE = 1{,}242 \text{ ft-lbs}$$

$$KE = 14{,}904 \text{ in-lbs}$$

Taking the kinetic energy of the impact as equal to the area under the load/deflection curve:

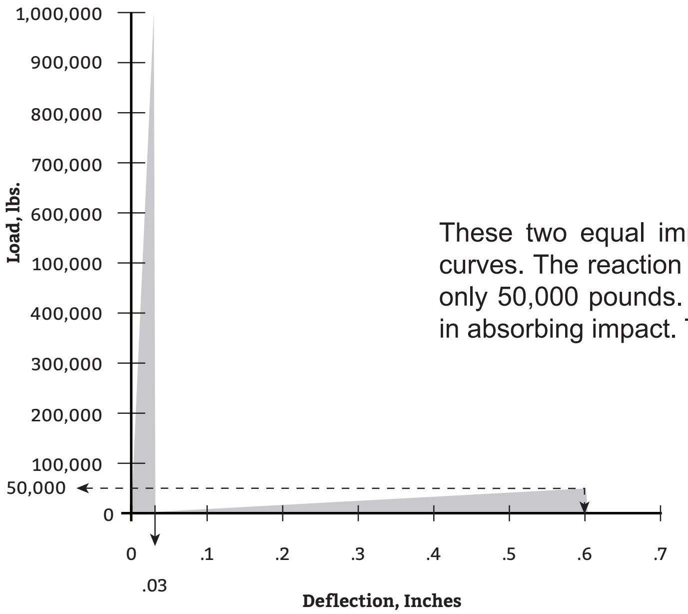
$$KE = 14{,}904 \text{ in-lbs}$$

$$KE = \frac{1}{2} Fd$$

$$14{,}904 \text{ in-lbs} = \frac{1}{2} \times 50{,}000 \text{ lbf} \times \text{deflection (in)}$$

$$d = 0.60 \text{ in}$$

This is the minimum deflection that we need so that we don't exceed the 50,000 pounds of force maximum. The loaded area of the bumper is 28.3 in², the bulge area is 56.5 in², therefore, the Shape Factor is .5. The maximum force of .60 inches is 20% of the 3 inch length. Therefore, the proper material will deflect at least 20% at 1,767 psi for a .5 shape factor. Referring to the static strain curves, we see that a 95A durometer (GC 1095) at .5 Shape Factor will deflect approximately 33% at 1,767 psi (we are allowing for an approximate 1.5 dynamic to static spring rate ratio). A test should be conducted to verify the actual deflection achieved in use.

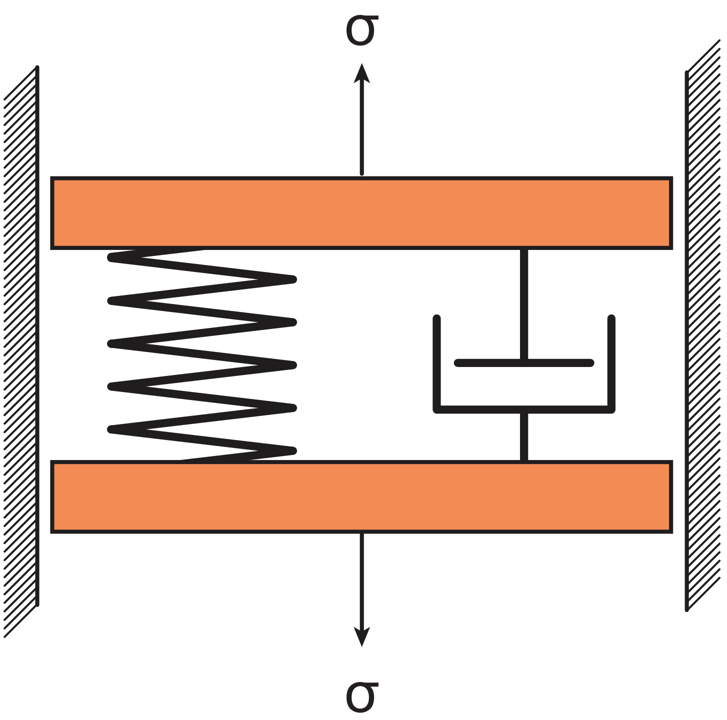


These two equal impact loads have the same area under load-deflection curves. The reaction force in one case is 1,000,000 pounds and in the other only 50,000 pounds. This graphically illustrates the importance of deflection in absorbing impact. The urethane in this case is 95A durometer (GC1095).

Hysteresis in Urethane

Let's examine the compression-deflection curve for a given compound at a given shape factor and record the stress-strain relationship.

As the piece is loaded, we arrive at one reproducible curve after three or four cycles. Now, if we record the curve generated during the unloading we see that not all the initial energy is returned. The area under the loading curve can be called the input energy. The area under the return curve can be considered the return of stored energy and the area between the two curves is the energy that is not returned but is converted to heat. This energy is converted to heat by hysteresis. This phenomenon is characteristic of all types of rubber, because rubber compounds are viscoelastic systems. See chart: stress-strain cycling of two 95A durometer urethanes.



The urethane elastomers consist of an elastic portion that stores energy and returns it and a viscous portion that captures energy and converts it to heat. It might help to consider the spring and dash pot experiments of Physics class. The spring represents the elastic response and dash pot the viscous response.

To some extent, the ratio of the elastic component to the viscous component can be altered by chemical manipulation during compounding, but both components are always present in a urethane compound. A high elastic to viscous ratio is common to highly resilient compounds. A low ratio is typical of a "dead" or low resilience compound. In design, the viscoelastic nature of urethanes must be taken into account. A low ratio compound converts more input energy to heat than a high ratio compound on each deflection cycle.

By the same token, if the frequency of deflection is very low, the low resilience compound will absorb more impact. This is an important consideration because excess heat is the Achilles Heel of polyurethane. The range of the coefficient of thermal conductivity (K) for polyurethanes is quite low, as you can see.

$$1.7 \text{ to } 3.5 \times 10^{-4} \frac{cal \bullet cm}{sec \bullet cm^2} \ {}^\circ C \text{ or } 0.5 \text{ to } 1.2 \ \frac{BTU}{hr \bullet ft^2 \bullet \frac{{}^\circ F}{in}}$$

Due to the inherent low thermal conductivity of urethane and hysteretic heat build-up, part designers must address ways to generate less heat under cyclic loading conditions. This is typically accomplished by reducing the deflection (strain) per cycle, by increasing the compression modulus of the elastomer, or increasing the shape factor. Reducing the stress per unit area is another possible approach. The selection of compounds and stoichiometry coupled with design can alleviate many potential heat build-up problems.

Isolating Vibration Using Polyurethane

The dynamic properties of polyurethane in combination with its high load-bearing capacity make it an excellent choice for a number of vibration isolation applications. To get started, let's go over some definitions.

Natural Frequency

It is usually expressed in Hertz (Hz) or cycles per second:

$$f_n = 3.13 \sqrt{\frac{1}{\text{Static Deflection}}}$$

Frequency Ratio

The Forcing Frequency, f_f (sometimes called disturbing or driving frequency), divided by the Natural Frequency, f_n, is the ratio that indicates the effectiveness of a vibration isolator. The Forcing Frequency units are Hertz or cycles per second.

$$\text{Frequency Ratio} = \frac{f_f}{f_n}$$

Damping

This is the hysteresis (viscous) component of a polyurethane isolator. It is this hysteresis characteristic that converts mechanical energy into heat which is then dissipated. In free vibration a fair percentage of the input energy is dissipated in the form of heat during each cycle causing the vibration to die out.

The Damping Ratio, C/C_{cr} is used to indicate the amount of damping in a system. C/C_{cr} is affected by temperature and preload. Typically for most urethanes it can be varied from a low of .05 for highly resilient compounds to .15 for the low resilience urethanes. Using the above information and the Transmissibility Curve shown on the next page we can design urethane isolators.

Example

A rotary compressor weighing 5,000 lbs. is to be supported on four sandwich type mounts (urethane pad bonded between metal plates). The motor operates at 1,800 rpm. At least 75% of the disturbing vibratory forces must be isolated; that is, the transmissibility is to be less than 25%.

First, assume a Damping Ratio of .1, we need a starting point to get into the ballpark and we can always come back and change it. Next, by examination of the Transmissibility Curve we see that to be at 25% Transmissibility with a C/C_{cr} of .1 the Frequency Ratio (f_f/f_n) should be 2.5 or higher.

$$\text{Frequency Ratio} = 2.5 = 30Hz/f_n = (1{,}800 \text{ rpm} = 30Hz)$$

$$f_n = 12Hz$$

Therefore the system natural frequency must be 12Hz (or lower).

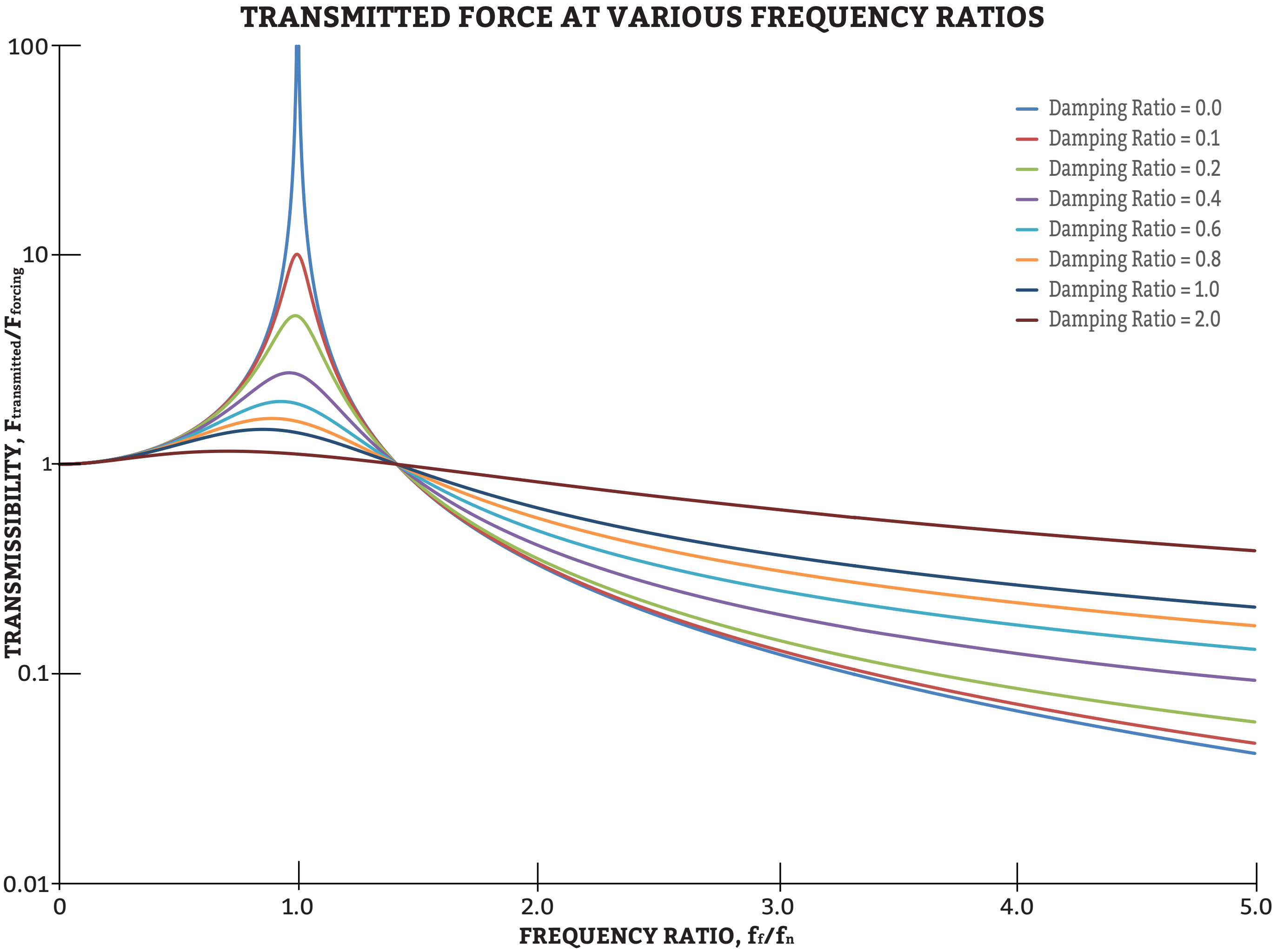
$$f_n = 3.13 \sqrt{\frac{1}{\text{Static Deflection}}}$$

$$12 = 3.13 \sqrt{\frac{1}{\text{Static Deflection}}}$$

$$\text{Static Deflection} = 0.068 \text{ in}$$

Now we know that each mount must deflect .068 inches under the total 65,000 lbs. or 1,250 lbs. per mount in order to have a natural frequency of 12Hz.

Next, we need to design an element with .068" deflection at 1,250 lbs. In consideration of the long term static load plus the possible heat generation due to hysteresis let's use a free height of .75 inches of urethane. That means that the .068" deflection is a 9% deflection. GC 1285 is a good material choice for this type application. By making a few trial and error calculations at different pad cross sections and using the Stress-Strain Curves we arrive at a 2" x 2" urethane pad, with a Shape Factor of .67, and a compressive stress of 313 psi produces a deflection of 10% of 0.75 inches. A test should be performed to verify the calculated results.

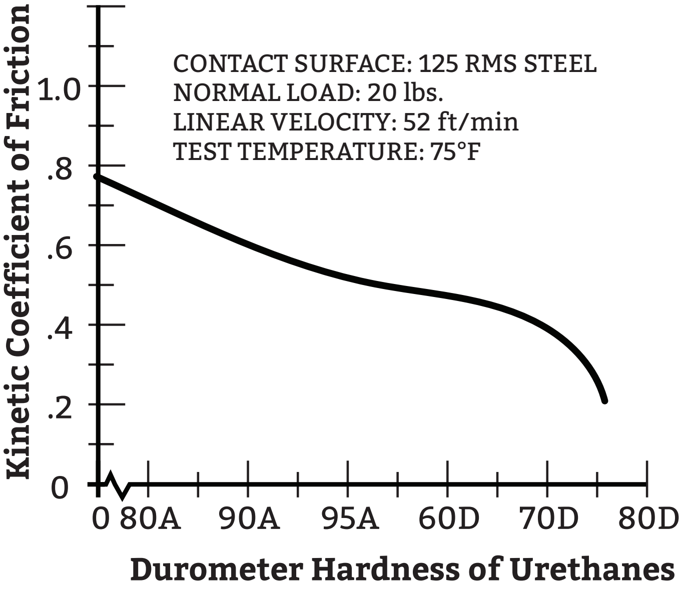


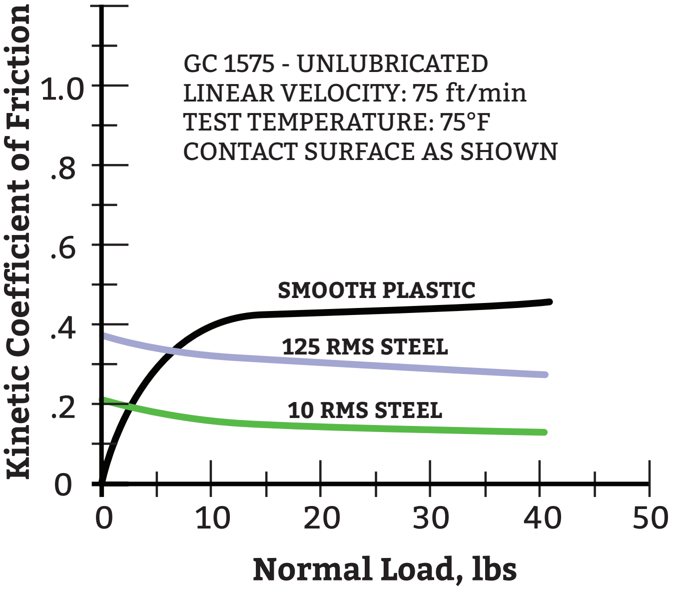
5 Reasons You Can Count On Gallagher Corporation

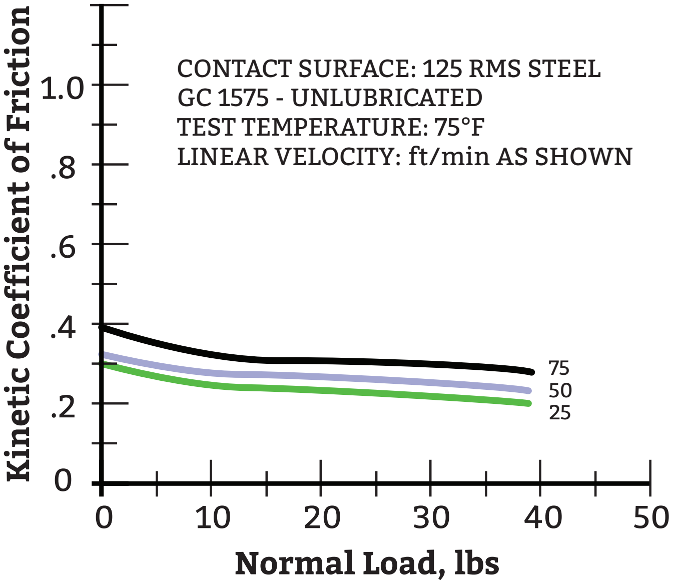
1. ***We have decades of application engineering experience.***
2. ***We are financially sound, with no debt.***
3. ***We have the capacity and staff to take on your additional business.***
4. ***We are a progressive manufacturer with plans to stay in business a very long time.***
5. ***We are unequivocally serious about meeting our commitments to our customers.***

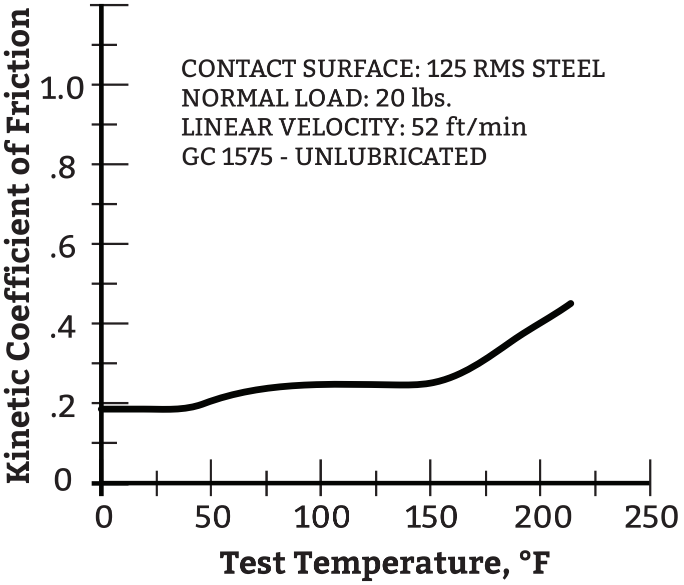
Polyurethane Coefficient of Friction

The coefficient of friction between polyurethane elastomers and non-lubricated surfaces decreases with increasing hardness. Since harder elastomers have the lowest coefficient of friction, these materials perform the best where sliding abrasion resistance is necessary. The softer compounds are ideal where friction is required, such as a urethane drive wheel.







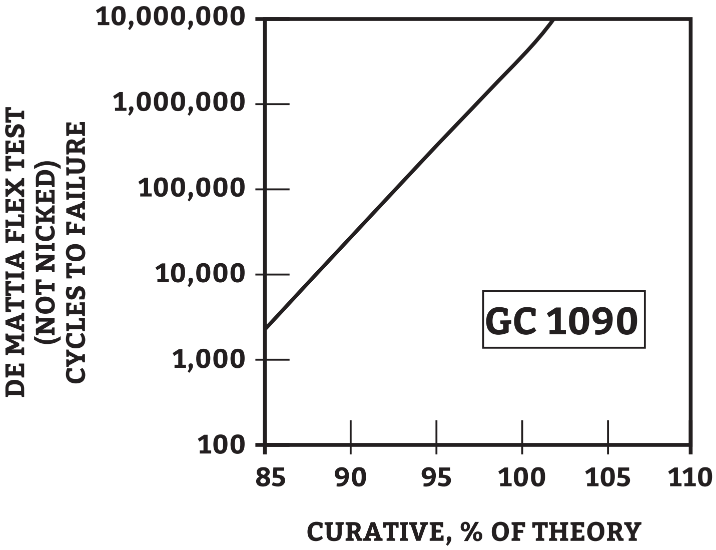


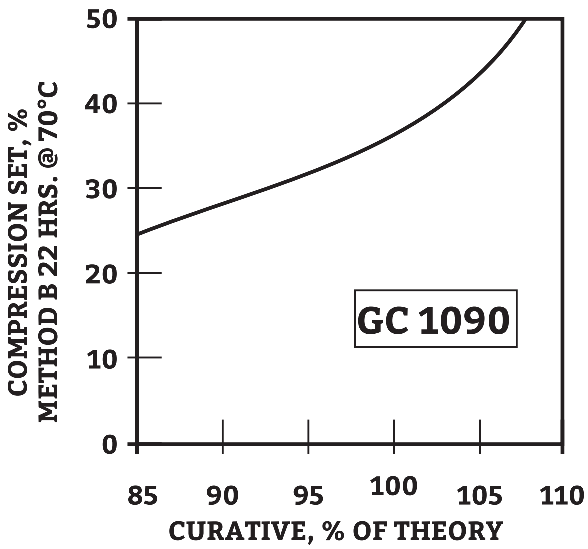
Polyurethane Stoichiometry

Stoichiometry is the chemical relationship of the amount of reactive elastomer polymer to the amount of curing agent used.

Selection of proper stoichiometry is our responsibility, it plays an all important part in compression set resistance, cut and tear resistance and flex fatigue resistance. When higher stoichiometry is used, flex fatigue resistance will be higher; however, the part will build up heat faster due to hysteresis. When lower stoichiometry is used, the finished material will have reduced compression set and will heat up slower due to hysteresis. The drawback to lower stoichiometry is that the material will be less resistant to flex fatigue and cuts or tears.

It's important to try to establish whether heat build-up or flex fatigue resistance is the more important property needed for best application performance. Stoichiometry can be used to our advantage for problem solving specific applications





These graphs show the broad effect of stoichiometry on the physical properties of 90A durometer elastomer (GC 1090). (click to enlarge)

Urethane Molding Tolerances

Often, Gallagher Corporation receives prints detailed to tolerances that are unrealistic for the applications. The tighter the tolerances, after all, the higher the cost of the part. Keep in mind that on non-critical dimensions, it's best to consult us on what is practical for molding and optimum part cost.

If there is a requirement for very close tolerances on certain dimensions, we can achieve them through tooling design, either by sizing development of the tooling or by secondary machining steps after the part is made.

Unlike metals, polyurethanes have a very high coefficient of thermal expansion (0.8 - 1.4 $\times$ 10^{-4}/in/in/°F. If a part is made to a ±.005 inch tolerance, as measured at 75°F (24°C), it could be out of tolerance at 40°F (5°C) or at 110°F (43°C).

Here are some guidelines for the tightest "as molded" tolerances:

Tightest "As Cast" Tolerances	
0 - 1 in (0 - 25mm)	± .005 in (± .1mm)
1 - 36 in (25 - 915mm)	± 0.5%
> 36 in (> 915mm)	± 0.7%

Physical Constants of Polyurethane Elastomers

Compound	Specific Gravity	Thermal Conductivity	Linear Coefficient of Thermal Expansion		
			-32°F to +32°F (-35°C to 0°C)	32°F to 75°F (0°C to 24°C)	75°F to 212°F (24°C to 100°C)
GC1285	1.08	.92	-	1.1×10^{-4}	-
GC1090	1.11	.92	1.4×10^{-4}	$.95 \times 10^{-4}$	$.95 \times 110^{-4}$
GC1095	1.13	.86	1.3×10^{-4}	$.89 \times 10^{-4}$	$.9 \times 110^{-4}$
GC1260	1.16	.80	1.0×10^{-4}	$.87 \times 10^{-4}$	$.85 \times 110^{-4}$
GC1275	1.19	.75	$.8 \times 10^{-4}$	$.83 \times 10^{-4}$	$.8 \times 110^{-4}$
GC855	1.22	.75	1.4×10^{-4}	1.0×10^{-4}	$.9 \times 110^{-4}$
GC970	1.25	.80	1.3×10^{-4}	$.93 \times 10^{-4}$	$.9 \times 110^{-4}$
GC485	1.24	.80	1.2×10^{-4}	1.1×10^{-4}	$.8 \times 110^{-4}$
GC980	1.25	.80	1.2×10^{-4}	$.91 \times 10^{-4}$	$.8 \times 10^{-4}$
	see note 1	see note 2		see note 3	

NOTES:

1. Specific Gravity can be interpreted in terms of grams per cubic centimeter.
2. Thermal Conductivity $= 1.7 \text{ To } 3.5 \times 10^{-4} \frac{\text{cal-cm}}{\text{sec cm}^2} \text{°C} \quad \left(0.5 \text{ To } 1.2 \frac{\text{BTU}}{(\text{hr})(\text{ft}^2)(\text{°F/in})}\right)$
3. The coefficient of linear thermal expansion is the change per length per degree F. The expansion of all rubbers is about the same order of magnitude, approximately 10 times that of steel. Thermal contraction may also be calculated using the coefficients to determine the shrinkage at low temperatures.

Gallagher Capabilities at a Glance

1. ***Custom molding of cast polyurethane***
2. ***Product design and development***
3. ***Moldmaking and machining***
4. ***Injection molding – thermoplastic polyurethane (TPU), thermoplastic elastomers, and glass reinforced plastics***
5. ***ISO 9001:2008 certified***

Section 4: The Design Process

7 Steps to Successful Polyurethane Part Design

The following steps in order yield the best approach to design and problem solving. We encourage you to contact us for help every step of the way.

1. Prioritize the properties that are necessary for performance in a given application.
2. Material characterization – bring us in at this stage. The urethane elastomers can be tailored to an almost infinite variety of material properties. We can assist in the selection. There is no perfect elastomer for all applications, but there are usually one or two choices that are worthy of prototype testing.
3. Establish a prototype test program simulating the operating conditions. Acceleration of testing by increasing cyclic rates or amplitudes beyond the application parameters always results in excessive heat build-up in urethanes and unsatisfactory data.
4. Modify the compound or design to correct any deficiencies noted in testing.
5. Set up a limited field trial and monitor results.
6. Modify compound and design if required.
7, Write a material specification for inclusion with design drawings.

Case Study: Polyurethane Part Design

In elastomer design development, we try to optimize the best properties for the intended service and minimize the interference of the undesired properties.

Analysis of Application Requirements

The key to successful design and application starts with analysis of the application and prioritizing those properties needed for best performance. In some cases, one property may be at the top of the list. In another, it may be at the bottom. It depends entirely on the application. The next step is the selection of candidate urethane elastomers that have a high potential for success. Then comes molding or machining of the elastomer to component design. Finally, the all-important prototype test.

Material Selection for Impact Bumper

A good example of the importance of the proper material selection is the choice that was made in the material for a particular impact bumper. This real-life application shows the interdependence of design/engineering selection.

A pre-loaded support pad capable of absorbing high impact force was required. In this case the bumper was to remain under a large static pre-load for years before a possible huge impact might be encountered.

It had to service the northern European climate with a fairly broad range of ambient temperature and humidity. It would come in contact with minor amounts of oil but no chemicals or solvents. Adhesion to metal was not needed and the pre-load would prevent oils or grease from getting into the interface between urethane and steel.

Resistance to compression set (or stress relaxation) was critical but resistance to fatigue from repeated cycles was not. Age resistance to weather, oxidation and ozone was important so that no loss in properties would be noted over a 25 year service life. Screening from ultraviolet light would be achieved by pigmenting the elastomer black.

The priority list for this bumper would read, in order:

1. Compression set resistance to 42 kips preload
2. High impact load-deflection properties to 84 kips at 4 inch travel
3. Relatively stable stress-strain curve from - 40°F to 160°F (-40°C to 71°C)
4. Oil and hydrolysis resistance, oxidation and ozone resistance

Given the list of parameters above, it is logical to select a compound that meets those requirements and proceed through the design process. Let's select GC 1090 as our starting compound. GC 1090 has a limit of 10% for long term static deflection.

By performing several iterations of different shapes at 10% deflection, we are able to arrive at an unbonded stack of sixteen GC 1090 pads (each 9 $^{3}/_{4}$" diameter x 1 $^{3}/_{16}$" thick) separated by fifteen $^{1}/_{4}$" thick steel plates. By using the urethane pads in series we are able to use the load bearing capacity of one pad combined with the total deflection of sixteen. A dynamic load of 84 kips would produce a deflection of approximately 4 inches. Drop hammer tests confirmed that the calculated deflections were within the allowable tolerance and several hundred assemblies are now in service.

Urethane Compound Specifications

The lesson to be learned from all foregoing discussion is that a successfully performing elastomer should be well documented by a meaningful specification.

Why? Because hardness alone is not a reliable specification. At the same hardness we produce many compounds with widely different performance characteristics. Good specifications are essential in competitive bidding and reliable consistency order to order. A good specification should contain data obtained by tests to ASTM standards.

Tested By ASTM Methods	
Hardness	D2240
Tensile Strength	D412
Elongation	D412
Modulus at 100% or 300%	D412
Tear Strength (DIE C)	D624
Tear Strength by D-470 (SPLIT)	D470
Specific Gravity	D792
NBS Abrasion Index	D1630

Note: Since the language of rubber technologists differs from that of the metallurgist, consult the glossary of terms. It's important to understand the differences.

We provide specification sheets on each of our compounds.

Where an application requires specific environmental performance, those requirements should also be listed. We're always willing to help our customers write specifications. Comprehensive specifications should be on the drawings before they go to the Purchasing Department for quotation requests.

Remember that the chemical structures we use are all premium performance compounds, with no fillers or extenders unless they serve a technical purpose. We never use additives as a way to reduce compound cost. Any reduction of physical and mechanical properties must be balanced with any cost advantages achieved. It is not possible to maximize all properties in one compound. Intelligent compromise is always required.

We have urethane elastomers which can meet the following military specifications:

- MIL-R 83397
- MIL-P 3065 PLUS ASTM D 2000
- MIL-R 45036 (AU/EU)
- MIL-R 45036 D (MR)
- MIL-M 24041
- ASTM-D 2000
- SAE-J 200
- MIL-R 15624
- MIL-M-I 46058
- MIL-M 24041
- MIL-C 24231

We also make urethane compounds which meet FDA and USDA requirements for contact with wet, dry, or oily foods. In addition some compounds meet or exceed flame resistance requirements of mine safety (MSHA). We use MIL-I 45208 for quality assurance.

Section 5: Finishing & Secondary Processes

Machining Cast Polyurethanes

Cast polyurethanes can be readily turned, sawed, drilled, ground and milled. We offer many engineering shapes of our compounds which can often be used to make prototypes or limited production quantities. It is important to note that the material presented here is a starting point. The wide variety of urethane compounds and their respective physical properties and characteristics creates a wide range of situations.

Harder urethanes – 90A and up – have a high degree of machinability. Lathe turning, fly-cutting, grinding, contouring and more are easily accomplished on conventional metal working equipment by machinists who are familiar with procedures for handling plastics.

Some different tools and techniques are required for compounds of 80A durometer and lower. The lower modulus compounds are typically machined by knifing, grinding and sanding. In some cases, however, they can be worked like higher modulus materials by "freezing" them with dry ice or liquid nitrogen.

Key Points to Remember When Machining Polyurethane

Urethanes have much lower thermal conductivity than metals, so heat generated by cutting tools stays close to the tool and raises the urethane surface temperature rapidly. This heat must be controlled. Melting can occur above 350°F (175°C). In addition to possible melting, heat generated by machining causes the part to reversibly expand. When the part cools, it shrinks and could become undersized.

Elastic Memory – Elastic recovery occurs in urethane both during and after machining. The cutting tool must provide clearance to compensate for this. Without compensation, expansion of the urethane as it passes the tool will result in increased friction between the cut surface and the cutting tool. Excess heat build-up will result. Elastic recovery after machining can result in smaller internal diameters and larger external diameters than were measured during cutting.

Modulus of Elasticity – Urethanes are compliant and can easily be distorted. It is possible to alter the shape of a urethane part by clamping or chucking it with too much force. This would cause the final machined shape to be distorted after the cuts have been made and the fixturing pressure was released. Care must be taken to hold parts securely, but to avoid distortion due to holding or cutting.

Softening Point – Gumming, poor finishes, and poor dimensional control will occur if excess heat is generated and allowed to accumulate. Proper tool geometry, feed rates, and cutting speed, in conjunction with coolants usually will overcome these problems. Water soluble cutting oils and/or light machining oils are good coolants for urethanes.

GENERAL SAFETY CONSIDERATIONS

When performing any machining or other secondary operations on urethanes, we recommend that all appropriate safety equipment as well as personal protective devices be utilized at all times.

Eye protection should consist of approved safety glasses with side shields or full goggles. A full face shield is recommended whenever chip pieces or work pieces could fly out and strike the operator in the face.

Fixturing is an extremely important aspect of machining urethane. Never attempt to start machining until you are positive that the fixturing is safe and secure. Improper fixturing during plunge cuts and contouring can cause the work piece to come out of the machine and injure the operator or a bystander.

CAUTION! Excessive heat can be generated by improper machining practices. If smoke is generated, the method must be immediately corrected. DO NOT inhale the smoke or grinding dust from urethane or any elastomer or plastic.

Cutting Polyurethane Parts

One of the best machines for sawing urethanes is a band saw. Long blades of 125 to 175 inches (3,175 to 4,445 mm) are desirable because they stay cooler and keep the urethane from melting. A band type we have found to work well is a 4 tooth per inch with raker set. A raker set blade is one that has its teeth alternating to the left and right of center. This type of blade reduces friction by removing chips from the kerf.

Band speeds in the range of 2,600 feet per minute work well on almost all hardnesses. Feed rate is controlled by hand, so it is operator dependent. Any moderate hand feed will suffice, but do not force the work. Keep hands well to the side of the saw blade; never in front of the saw.

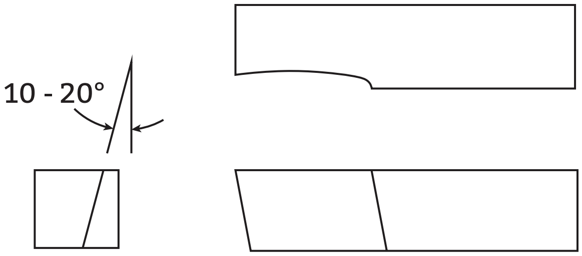
On softer urethane, a faster blade speed helps prevent the urethane from pulling down into the cut, rubbing on the blade, and building up heat. When cutting thin, low durometer sheet stock, the work must have some support. A sheet of cardboard, for example will help prevent the work piece form being pulled through the table slot by the blade.

When cutting 90A durometer and below, use a spray mist of water-soluble oil (50-50 mix) to help keep the heat down and to improve the finish.

Contouring Polyurethane Wheels, Rolls and Other Parts

Machining tapers, chamfers, grooves, and other surface configurations into wheels, rollers and other round parts all fall into the general category of contouring.

The tool works best when positioned .025 to .075 inches (.6 to 2 mm) below the center of the work piece. The chips should come off in a continuous ribbon. Try to keep the chip from wrapping around the work piece. If this occurs, stop, remove the urethane that wrapped around the work. Reduce the feed rate.



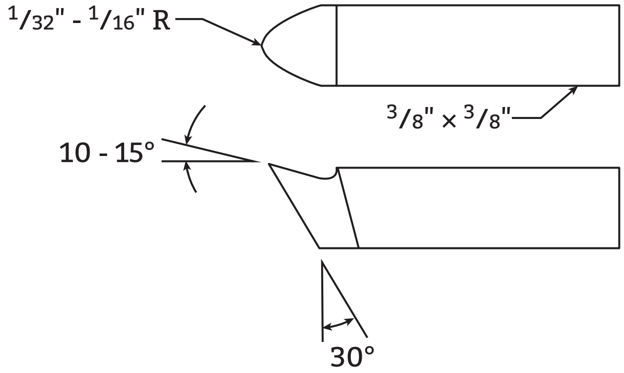
Safe fixturing of parts when contouring is very important. When contouring urethanes softer than 95A, use a tool with 15 to 30 degrees of top rake. Lathe speed depends on the O.D. of the part. In general, high rpm works best. Feeds should be slow until experience is achieved.

Note: When machining urethane, wear a full face mask.

Turning & Facing a Polyurethane Part

In general, use sharp tools, high turning speed, and slow to moderate feeds (depending on hardness). Cutting tools for urethane must have sharp, carefully honed cutting edges. Sharpen tools on a honing stone for a razor sharp edge on the sides, tip, and top of your tools. We have found success with both high speed and carbide tools.

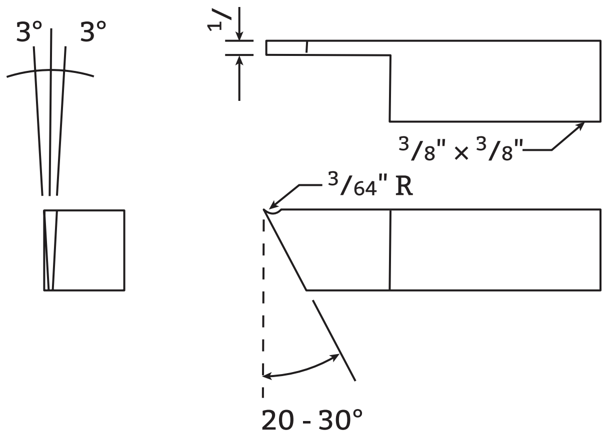
Tool clearances must be greater than those used for metal. The goal is to have little or no resistance as the tool travels through the urethane. The chip (material that is being cut away) should come off as a continuous strip or ribbon. A smooth surface on the top of your tool will aid in chip removal. This is very important to prevent the chip from wrapping back around the work piece. Good chip removal is also critical for heat removal and tool life.



Parting a Polyurethane Part

Tools that work well for parting are .060" to .100" (1.524 to 2.54 mm) wide with a 20 to 30 degree front rake and no top rake. A small 3/64" radius is ground into the top of the tool. Starting on the cutting edge, some side clearance is helpful. Three to five degrees is all that is usually needed.

The proper tool, feed and speed allow the chip to exit the cut with little resistance and heat buildup. Parting yields a good surface finish and is a useful variation for facing certain urethane parts.

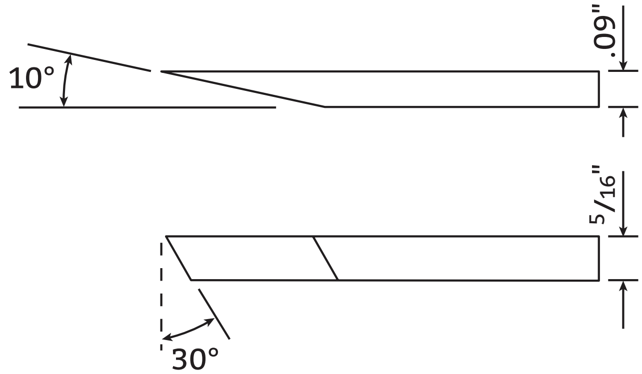


Knifing a Polyurethane Part

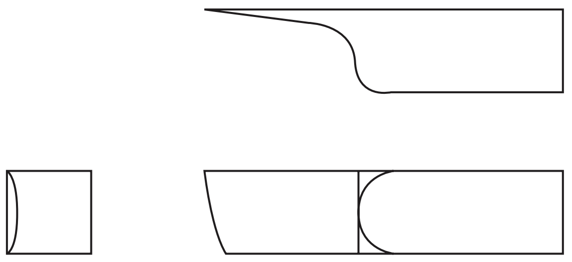
Knife cutting polyurethanes to close tolerances can be done without too much difficulty. The tool must be absolutely razor sharp and be as thin as possible. When knifing, the urethane will have a tendency to pull into the tool. This displacement of the material will cause a "dish" on the finished end of the part. The thinner the tool, the less the pulling effect on the cut edge. Lubricants also help reduce this tendency.

A good practice on thick cuts is to do a rough cut to remove the bulk of the material, then take a finishing cut to remove the final .025 to .050 of an inch.

We use two types of knifing tools; high speed steel is used on medium to hard urethane (70A to 95A). This type of tool must be very smooth and have a razor sharp point. All edges and surface behind the cutting point must be smooth to prevent the cut-off material from being pulled between the work piece and the tool. High turning speeds of 600 to 1000 rpm with rapid hand feed will yield an excellent surface finish. Carbide works best for medium and softer grades.



Knifing tool for softer urethanes (carbide)



Knifing tool for harder urethanes (H.S.S.).

Grinding a Polyurethane Part

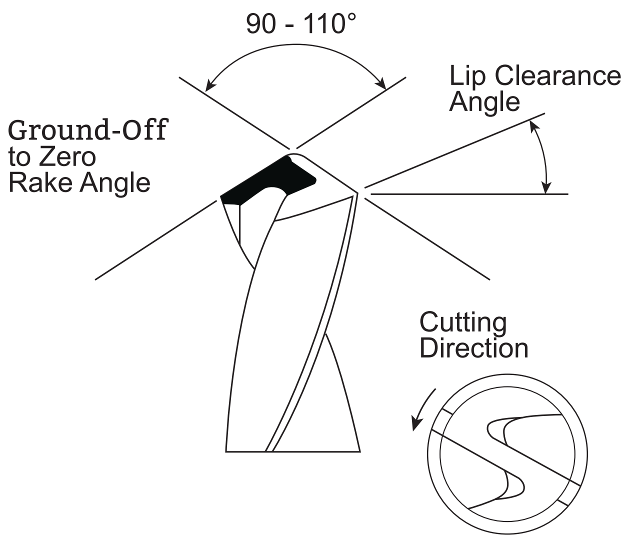
Urethanes 55A to 80A durometer can be ground successfully in an engine lathe using a tool post grinder. Use low turning speeds – below 150 rpm, with the lathe running in reverse. Start with the grinder feed rate set .005 inches per revolution. Use a slower feed to improve surface finish or to remove more material by taking a deeper grind.

We have found that a 46 grit wheel with slight radius on the leading edge works well. RPM of the wheel should be in the 2250 to 3250 range. Again, low work piece turning speed of 150 rpm is a good starting point. Fine abrasives can be used for final polishing.

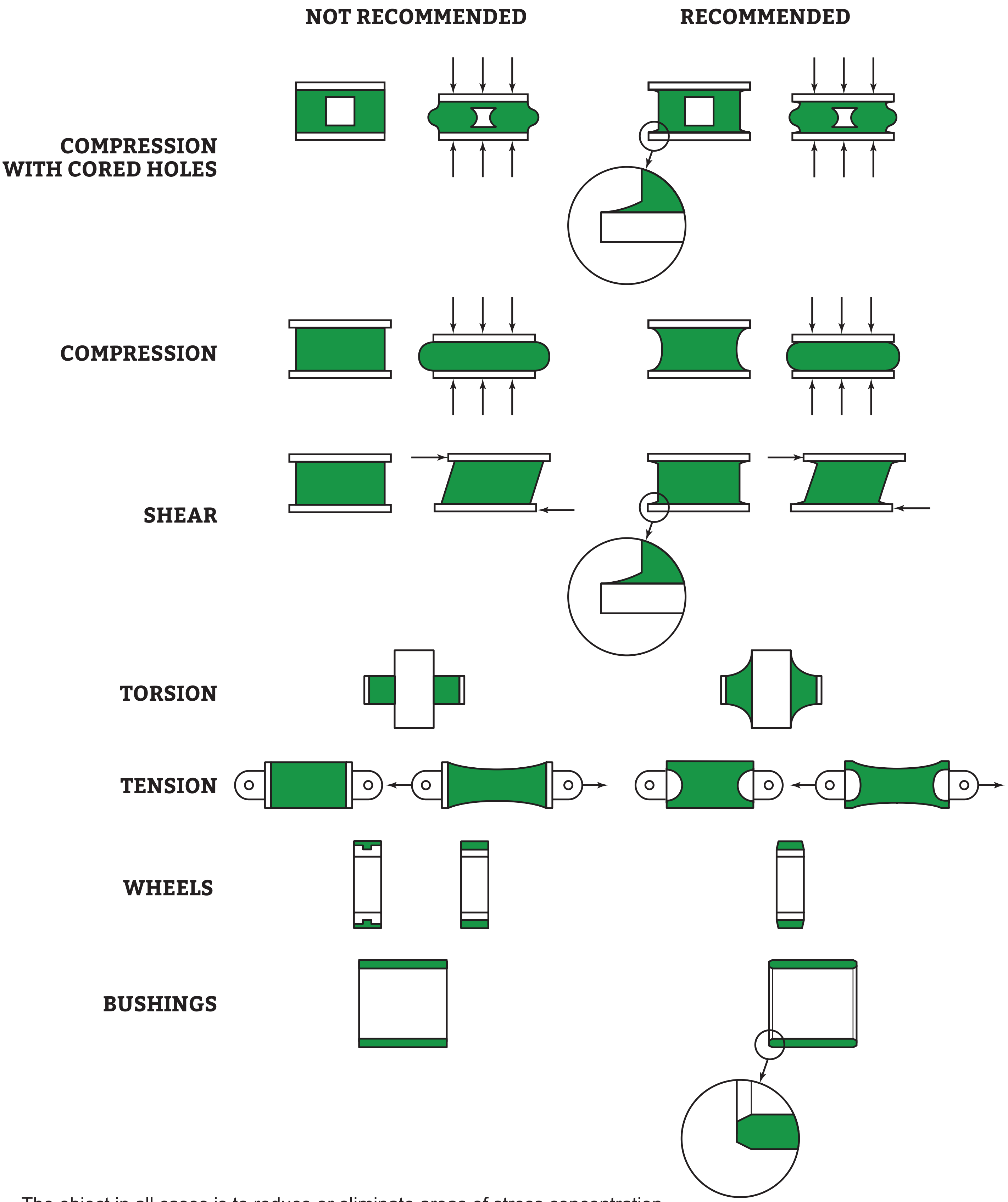
Urethanes above 80A durometer usually require some type of coolant; however, they can sometimes be ground dry. Water is a good coolant and can be applied with a brush or with a fine spray mist. We recommend that the grinder be equipped with a dust collector or the operator wear an approved dust mask when grinding or sanding urethanes

Drilling a Polyurethane Part

Slow spiral drills perform best because the large flute area permits free discharge of chips with a minimum of binding and heat build-up. Frequent retraction of the drill aids in eliminating chip blockage of the flutes.



Design Tips to Improve Service Life of Urethane Components Bonded to Metal.



The object in all cases is to reduce or eliminate areas of stress concentration.
Replace sharp edges with chamfers or radii.
Use designs which promote natural shaping of the urethane when under load

Section 6: Glossary

Urethane Design Glossary

Glossary of Terms

ASTM TEST METHODS

You will note that we refer to ASTM tests and test results frequently. We use ASTM tests to classify properties, but the limitations on the usefulness of the standard tests are well stated in ASTM D 394 and D 1630: "No relation between this test and service performance is given or implied..." As stated previously and repeated for emphasis: NEVER by-pass the all-important prototype and field test steps. However, once performance has been proven, relevant ASTM test data serves well in specification writing.

COMPRESSION

Stress on a material tending to cause deflection, since, in many instances, urethane elastomers can be considered incompressible. Because very little volume change occurs, we prefer to use the term "deflection." Cellular products such as urethane foam do compress because of the collapse of the air-filled cells.

ELASTOMER

The word is generally applied to the man-made rubbers. It's simply the contraction of the words "elastic polymer." Each of the elastomer classes is characterized by its own set of characteristics which make it useful.

HEAT BUILD-UP

This term, peculiar to the rubber industry, means the temperature rise within an elastomer body due to hysteresis and the low thermal conductivity of elastomers. Since the physical properties of urethanes are reduced as the temperature rises above 160F (70C), heat build-up is to be avoided. The amount of heat liberated per deformation cycle is proportional to the amplitude of the strain, the frequency of application and the duration of the condition. Designers can avoid heat build-up by constructive use of shape factor.

HYSTERESIS

Refers to the percent energy lost per cycle of deformation or 100% minus the resilience percent. Hysteresis is the result of inter-molecular friction and is manifested by conversion of mechanical energy to heat. See hysteresis page.

MODULUS OF ELASTICITY

In elastomers, as in steel, this term refers to the ratio of stress to the strain, produced by that stress. Within the region of low strain (up to 15%), an elastomer's stress-strain curve is almost linear and design calculations which assume stress proportional to strain may be made with tolerable error. Strains greater than 15% are far from proportional to stress. Modulus of elasticity in this engineering sense should not be confused with "modulus" which is rubber industry jargon for tensile stress and is applied when strains are much greater than 15%. Elastomers in general have two moduli of elasticity; static and dynamic, in as much as they have the peculiar property of behaving stiffer when vibrated or impacted. The term "modulus" when applied to steel is defined as the slope of the straight line portion of the stress-strain curve. In the case of elastomers, modulus is defined as the stress required to produce a given strain of say 300%, would be called the 300% modulus, and is not useful in calculations.

NATURAL FREQUENCY

The characteristic frequency of vibration for a particular spring-mass system after a force or displacement is applied and removed.

POLYURETHANE

An alternative term for urethane.

RESILIENCE

The resilience of elastomers subjected to and relieved of stress has been defined by the ASTM as the ratio of energy given up on recovery from deformation to the energy required to produce the deformation, expressed as a percent.

RUBBER

The term embraces a large group of materials which have the ability, under certain conditions, to undergo large deformations and recover almost completely and instantaneously on release of the deforming force. This elasticity is due to the repetition of long molecular chains and cross links of the base polymer. The "first" rubber came from the tree "HEVEA BRASILIENSIS" and was called Indian or natural rubber. Its use can be traced to the Mayan Indian culture. Since the 1930's, at least 16 different man-made rubbers with different, improved and controlled molecular structures have been developed. Familiar types are neoprene, nitrile, butyl, silicone and urethane.

SHAPE FACTOR

The ratio of the load area of an elastomer body subjected to a compressive load to the sum of the areas which are free to bulge. As the shape factor increases, the strain produced by given stress decreases. This is a critical consideration in avoiding heat build-up in dynamic applications. It is also important in static load bearing applications such as structural bearing pads where compressive stress relaxation versus time is to be avoided.

TANGENT DELTA

(TAN DELTA): A ratio of the loss modulus (viscous component of the elastomer) to the elastic modulus (storage component of the elastomer). A low tan delta means higher resilience and less hysteresis.

TENSILE PROPERTIES

These properties in steel are basic. They affect almost every design calculation for steel products and have a direct bearing on the product's serviceability. Tensile properties of elastomers, on the other hand, have much less, if any bearing on serviceability and almost never affect a design calculation. They do have some influence in high impact studies, however.

TENSION

Stress on a material tending to cause elongation.

URETHANE

The name given to a class of NCO (isocyanate) terminated resins with cross linking or chain extension intermediates called curing agents. Urethane is often used as an alternative term for Polyurethane. There are ten major groups of urethanes:

1. MDI-Polyesters: produce FDA dry and wet food grade urethanes in the normal hardness range from 85 Durometer A to 45 Durometer D. They are tough, abrasion resistant and tear resistant.
2. TDI-Polyester: produce urethanes from 50 Durometer A to 75 Durometer D which are tough, abrasion resistant, and with excellent oil and aliphatic solvent resistance.
3. MDI-Polyethers: produce urethanes with higher resilience, better impingement type abrasion resistance, good dynamic performance, improved hydrolysis resistance and excellent low temperature properties. Some are adaptable to FDA and USDA application for wet and dry food contact.
4. TDI-Polyethers: have excellent low temperature and dynamic properties, microbial resistance and long term water resistance.
5. TODI Polycaprolactone: Excellent heat resistance, hydrolysis resistance and superior mechanical properties.
6. PPDI: Terminated polyesters and polyethers offer superior performance at higher temperatures.
7. MDI: Diphenylmethane Diisocyanate
8. TDI: Toluene Diisocyante
9. PPDI: Paraphenylene Diisocyanate
10. TODI: Toluidine Diisocyanate

Taken together, urethanes possess:

- Oil, water and weather resistance, ozone and oxidation resistance, and resistance to many chemicals. Some are radiation, fungus and bacteria resistant.
- High tensile and tear strength compared to other elastomers.
- Outstanding abrasion resistance compared to metals, plastics and other elastomers.
- Higher load bearing capacity than other elastomers. Higher impact resistance and resilience than plastics.
- Excellent retention of properties at very low temperatures and at temperatures up to 220°F (104°C). (Bonded to metal to 160°F (71°C).

YOUNG'S MODULUS

Alternative term for modulus of elasticity. It is the slope of the linear portion of the stress-strain curve of the elastomer in tension or compression.

Typical Physical Properties of Gallagher Cast Urethanes

Compound	ASTM Test Method	GC 855	GC 965	GC 970	GC 980	GC 485	GC 1285	GC 1090	GC 1095	GC 1560	GC 1575
Hardness											
Durometer A	D 2240	55	65	73	80	85	85	90	95	—	—
Durometer D	D 2240	—	—	25	30	35	35	40	50	60	71
Tensile Modulus, psi (MPa)											
at 50% extension	D 412	125 (0.9)	130 (0.9)	150 (1.0)	225 (1.6)	575 (4.0)	300 (2.1)	500 (3.5)	900 (6.2)	1200 (8.3)	2000 (138)
at 100% extension	D 412	270 (1.9)	280 (1.9)	300 (2.1)	530 (3.7)	1100 (7.6)	700 (4.8)	1100 (7.6)	1800 (12.4)	2400 (16.6)	4000 (27.6)
at 300% extension	D 412	520 (3.6)	390 (2.7)	1600 (11.0)	1000 (6.9)	1600 (11.0)	1200 (8.3)	2100 (14.5)	3400 (23.5)	8000 (55.2)	—
Ultimate Tensile Strength, psi (MPa)	D 412	3800 (26.2)	3500 (24.2)	5000 (34.5)	6000 (41.4)	7500 (51.8)	4400 (30.4)	4500 (31.1)	5000 (34.5)	8500 (58.7)	8500 (58.7
Ultimate Elongation, %	D 412	450	530	700	625	550	580	450	400	320	250
Tear Strength, pli (kN/m)											
Die C	D 624	190 (33.3)	180 (31.5)	240 (42.0)	370 (64.8)	430 (75.3)	400 (70.0)	240 (42.0)	500 (87.5)	465 (81.4)	1000 (175.0)
Split Tear	D 470	15 (2.6)	25 (4.4)	110 (19.3)	225 (39.4)	235 (41.1)	85 (14.9)	75 (13.1)	150 (26.3)	135 (23.6)	145 (25.4)
Compression Set, % after 22 hours at 158°F (70°C)											
Method B, 25% deflection	D 395	5	8	30	30	27	35	27	25	—	—
Method A, 1350 psi (9,3 MPa)	D 395	—	—	—	—	—	—	—	5.4	4.8	1.8
Resilience (rebound), %	D 2632	33	30	30	30	40	50	45	40	42	50
NBS Abrasion Index, %	D 1630	100	120	140	150	250	160	175	300	370	500
Specific Gravity	D 792	1.22	1.16	1.25	1.25	1.24	1.08	1.11	1.13	1.16	1.19
Young's Modulus, psi (MPa)		750 (5.2)	750 (5.2)	1800 (12.4)	4000 (27.6)	4700 (32.4)	4900 (33.8)	5100 (35.2)	10000 (69.0)	30000(207.0)	63000(434.7)
Brittleness Temperature, °F (°C)	D 2137	-34 (-37)	-70 (-57)	-42 (-41)	-34 (-37)	-31 (-35)	<-94 (<-70)	<-94 (<-70)	<-94 (<-70)	-65 (-55)	-65 (-55)
Coefficient of Thermal Expansion, in./in./°F		$10x10^{-5}$	$10x10^{-5}$	$9.3x10^{-5}$	$9.0x10^{-5}$	$11.0x10^{-5}$	$11.0x10^{-5}5$	$9.5x10^{-5}$	$8.9x10^{-5}$	$8.7x10^{-5}$	$8.3x10^{-5}$
DC Volume Resistivity, ohm-cm	D 257	—	—	—	$1.5x10^{10}$	$2.0x10^{11}$	—	$4.8x10^{11}$	$3.7x10^{12}$	$2.7x10^{13}$	$2.0x10^{14}$

PRECISION POLYURETHANE MOLDING

YOUR TOUGHEST DEMANDS - DELIVERED.

For over five decades, OEMs have turned to Gallagher Corporation because we consistently deliver the custom, critical polyurethane parts they need to succeed. Not every molder can handle the complexities of polyurethane molding, but our experienced engineers welcome every challenge.

Continuous Advancements in Polyurethane Expertise and Equipment

Bring us even the trickiest requirements of your most important components, and time after time, we turn them into success at our 100,000-square-foot, ISO-certified facility in Gurnee, Ill. Meanwhile, as your demands keep getting tougher, we're always reinvesting in our business, constantly enhancing our expertise and continuously improving our operations with new machinery, new processes and new materials to meet your evolving needs.

It's all part of a culture of commitment to your needs that you'll find only when you partner with Gallagher … where you can be confident that you'll always have your toughest demands – delivered.

A Wide Range of Polyurethane Molding Processes

Based on the size, quantity, and engineering requirements of your application, Gallagher delivers on your toughest demands using cast liquid techniques or injection molding.

A versatile range of processing machinery allows us to work on unique, one-of-a-kind projects as well as high-volume OEM components. We're constantly investing in better, faster, more efficient technologies to meet evolving needs and help you stay ahead in an increasingly competitive global market.

Cast Urethane

Every day, we process up to 40 different cast urethane compounds, which can be molded into hundreds of different products.

Our advanced machinery accurately maintains both temperature and flow rate of the liquid components, ensuring that the mixed compound is optimum and consistent. Because the cast urethane is a liquid, we can gravity-fill molds with little or no pressure. This type of tooling is generally less expensive – great for prototyping and short- to medium-production runs. We can also pressure fill molds directly from the mixing machine, centrifugally mold, compression mold and mold under vacuum.

Injection Molding

Gallagher offers a wide range of thermoplastic urethanes, glass filled urethane, TPR, polycarbonate and nylon. Processed via injection molding, thermoplastics combine great physical properties and cost-effectiveness on medium- and high-volume production runs.

Insert Molding

Using either of the above processes, we can mold to inserts such as bearings, wheel and roller hubs, threaded fasteners, metal plates, and shafts. The insert can be made from aluminum, steel, stainless steel or plastic.

Disclaimer: The information presented this document is provided as reference material only. It is not specific engineering advice related to your particular requirements. Contact Gallagher or review the data with your own engineer to confirm applicability.