Teflon™ PTFE
Fluoropolymer Resins

Properties Handbook
# Table of Contents

**Introduction** ........................................................... 4  
**Typical Properties** ................................................ 5  
**Patents** .................................................................... 5  
**Effects of Processing** ............................................. 5  
  Dielectric Strength ....................................................... 7  
  Tensile Strength and Ultimate Elongation ...................... 7  
  Specific Gravity ........................................................... 8  
  Macroscopic Flaws ...................................................... 8  
  Microscopic Voids ..................................................... 9  
  Visual Inspection ......................................................... 9  
  Dye Penetrants ........................................................... 9  
  Specific Gravity Comparisons ...................................... 9  
  Crystallinity and Molecular Weight ............................... 9  
  Practical Crystallinity Limits ....................................... 9  
  How to Specify Typical Fabricated Parts ....................... 10  
  Suggested Test Methods for Various Shapes ............... 10  
**Strength and Stiffness** ............................................ 12  
  General Characteristics .............................................. 12  
  Design Considerations .............................................. 12  
  Strength and Stiffness .............................................. 12  
  Tensile Stress ............................................................ 13  
  Compressive Stress ................................................... 13  
  Shear Stress .............................................................. 13  
  Poisson's Ratio .......................................................... 13  
  Modulus of Elasticity .................................................. 13  
**Creep and Cold Flow** .............................................. 20  
  Apparent Modulus of Elasticity ................................... 20  
  Stress Relaxation ....................................................... 20  
  Compressive Recovery ............................................. 20  
  Recommendation for Gasket Design ......................... 21  
**Effect of Temperature, Fatigue, and Impact** ............ 27  
  Thermal Expansion .................................................... 27  
  Low Temperature Properties ...................................... 27  
  Thermal Conductivity and Specific Heat ..................... 27  
  Heat Distortion .......................................................... 27  
  Elastic Memory .......................................................... 27  
  Decomposition at Elevated Temperatures ................... 29  
  Impact ........................................................................... 29  
**Hardness and Friction** ......................................... 29  
  Hardness ................................................................. 29  
  Friction (Granular) ..................................................... 29  
**Abrasion and Wear (Granular)** ............................. 30  
**Electrical Properties** ........................................... 32  
  Dielectric Constant .................................................... 32  
  Dissipation Factor ..................................................... 32  
  Dielectric Strength .................................................... 32  
  Surface Arc-Resistance .............................................. 33  
  Volume and Surface Resistivity .................................. 33  
**Other Properties** .................................................. 33  
  Weathering ............................................................... 33  
  Miscellaneous ......................................................... 33  
**Chemical Properties** ............................................ 33  
  Resistance to Chemical Attack ................................... 33  
  Permeability ............................................................. 33  
**Forming and Fabrication** ...................................... 33  
  Choose Correct Working Speeds ............................... 34  
  Properly Shape and Use Tools .................................. 34  
  Rules for Dimensioning and Finishing ....................... 35  
  Closer Tolerances .................................................... 35  
  Measuring Tolerances .............................................. 35  
  Surface Finishes ...................................................... 35  
**Safe Handling** ................................................... 35  
**Typical Applications** ............................................ 36  
**References** .......................................................... 38
Introduction

Teflon™ is a registered trademark of Chemours for its fluoropolymer resins. Teflon™ PTFE fluoropolymer resins are part of the family of fluorine-based products that also includes Teflon™ FEP and Teflon™ PFA and Tefzel™ fluoropolymer resins. These materials can be used to make a variety of articles having a combination of mechanical, electrical, chemical, temperature, and friction resisting properties unmatched by articles made of any other material. Commercial use of these and other valuable properties combined in one material has established Teflon™ PTFE fluoropolymer resins as outstanding engineering materials for use in many industrial and military applications. Teflon™ PTFE fluoropolymer resins may also be compounded with fillers or reinforcing agents to modify their performance in use.

The design and engineering data presented in this handbook are intended to assist the design engineer in determining where and how Teflon™ PTFE fluoropolymer resins may best be used. It is recommended that the design engineer work closely with an experienced fabricator because the method of fabrication may markedly affect not only production costs, but also the properties of the finished article.
Typical Properties

Table 1 lists physical property data relating to Teflon™ PTFE fluoropolymer resins. All properties presented in this handbook should be considered as typical values and are not to be used for specification purposes.

Patents

A large number of existing patents relate to various Teflon™ fluoropolymer resins, but no attempt has been made in this publication to refer to any of these patents by number, title, or ownership. The descriptions of a process, an apparatus, a composition, or any article may fall within a claim of an existing patent, but we do not intend that such a description should induce anyone to infringe any existing patent. It is the responsibility of the prospective user of Teflon™ fluoropolymer resins to determine whether his/her use constitutes infringement or noninfringement of any patent.

Effects of Processing

Teflon™ PTFE fluoropolymer resins are tetrafluoroethylene polymers, usually fabricated into parts by cold-forming and sintering techniques. Teflon™ PTFE fluoropolymer resins have a continuous service temperature of 260 °C (500 °F). Much higher temperatures can be satisfactorily sustained for shorter exposures.

Various physical properties can be obtained with Teflon™ PTFE fluoropolymer resins by varying the processing technique. Teflon™ PTFE fluoropolymer resins are versatile and can, within limits, be “tailored” to provide fabricated parts with particular physical properties.

Processing can have more impact on the performance of parts made from Teflon™ PTFE fluoropolymer resins than for those made from other types of polymers. For example, preforming pressure, sintering time, cooling rate, void content, and crystallinity level can have a significant effect on certain end-use physical properties, such as tensile properties, permeability, and dielectric strength. Table 2 lists features of Teflon™ resins that are relatively independent of fabrication conditions.

Table 2. Properties Relatively Independent of Fabrication Conditions

<table>
<thead>
<tr>
<th>Chemical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical resistance to corrosive reagents</td>
</tr>
<tr>
<td>Nonsolubility</td>
</tr>
<tr>
<td>Long-term weatherability</td>
</tr>
<tr>
<td>Nonadhesiveness</td>
</tr>
<tr>
<td>Nonflammability</td>
</tr>
<tr>
<td>Electrical Properties</td>
</tr>
<tr>
<td>Low dielectric constant</td>
</tr>
<tr>
<td>Low dissipation factor</td>
</tr>
<tr>
<td>High arc-resistance</td>
</tr>
<tr>
<td>High surface resistivity</td>
</tr>
<tr>
<td>High volume resistivity</td>
</tr>
<tr>
<td>Mechanical Properties</td>
</tr>
<tr>
<td>Flexibility at low temperatures</td>
</tr>
<tr>
<td>Low coefficient of friction</td>
</tr>
<tr>
<td>Stability at high temperatures</td>
</tr>
</tbody>
</table>
## Table 1. Typical Properties of Teflon™ PTFE Fluoropolymer Resins

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Method</th>
<th>Unit</th>
<th>Teflon™ PTFE Granular Resin</th>
<th>Fine Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength, 23 °C (73 °F)</td>
<td>D4894/4895</td>
<td>MPa (psi)</td>
<td>31.0 (4,500)</td>
<td>20.7 min. (3,000 min.)</td>
</tr>
<tr>
<td>Elongation, 23 °C (73 °F)</td>
<td>D4894/4895</td>
<td>%</td>
<td>400</td>
<td>200 min.</td>
</tr>
<tr>
<td>MIT Flex, 2 kg load, 10 mil</td>
<td>D2176</td>
<td></td>
<td>Did not break at 10⁶ cycles</td>
<td></td>
</tr>
<tr>
<td>Flex Modulus, 23 °C (73 °F)</td>
<td>D790</td>
<td>MPa (psi)</td>
<td>345–620 (50,000–90,000)</td>
<td>275–620 (40,000–90,000)</td>
</tr>
<tr>
<td>Stretching Void Index</td>
<td>D4895</td>
<td></td>
<td>—</td>
<td>15–200+</td>
</tr>
<tr>
<td>Impact Strength, Izod</td>
<td>D256</td>
<td>J/m (ft·lb/in)</td>
<td>80 (1.5)</td>
<td>133–267 (2.5–5)</td>
</tr>
<tr>
<td>Impact Strength, Izod</td>
<td>D256</td>
<td></td>
<td>21 °C (70 °F)</td>
<td>106 (2)</td>
</tr>
<tr>
<td>Impact Strength, Izod</td>
<td>D256</td>
<td></td>
<td>24 °C (75 °F)</td>
<td>160 (3)</td>
</tr>
<tr>
<td>Impact Strength, Izod</td>
<td>D256</td>
<td></td>
<td>77 °C (170 °F)</td>
<td>&gt;320 (&gt;6)</td>
</tr>
<tr>
<td>Impact Strength, Izod</td>
<td>D256</td>
<td></td>
<td>204 °C (400 °F)</td>
<td>No break</td>
</tr>
<tr>
<td>Hardness, Durometer</td>
<td>D2240</td>
<td>Shore D</td>
<td>55</td>
<td>50–65</td>
</tr>
<tr>
<td>Coefficient of Linear Thermal Expansion per °C (°F), 23–80 °C (73–140 °F)</td>
<td>E228</td>
<td>mm/mm·°C (in/in·°F)</td>
<td>10 x 10⁻³ (7 x 10⁻³)</td>
<td>—</td>
</tr>
<tr>
<td>Thermal Conductivity, 4.6 mm (0.18 in)</td>
<td></td>
<td>W/m·K (Btu/in·hr·ft²·°F)</td>
<td>0.25 (1.7)</td>
<td>—</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>D4591</td>
<td>kJ/kg·K (Btu/lb·°F)</td>
<td>20 °C (68 °F)</td>
<td>1.4 (0.33)</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>D4591</td>
<td></td>
<td>40 °C (104 °F)</td>
<td>1.2 (0.29)</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>D4591</td>
<td></td>
<td>150 °C (302 °F)</td>
<td>1.3 (0.31)</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>D4591</td>
<td></td>
<td>260 °C (500 °F)</td>
<td>1.5 (0.37)</td>
</tr>
<tr>
<td>Thermal Instability Index</td>
<td>D4894/4895</td>
<td></td>
<td>50 max.</td>
<td>50 max.</td>
</tr>
<tr>
<td>Deformation Under Load, 23 °C (73 °F)</td>
<td>D621</td>
<td>%</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Heat Deflection Temperature</td>
<td>D648</td>
<td>°C (°F)</td>
<td>450 kPa (66 psi)</td>
<td>73 (160)</td>
</tr>
<tr>
<td>Heat Deflection Temperature</td>
<td>D648</td>
<td>°C (°F)</td>
<td>1800 kPa (264 psi)</td>
<td>45 (115)</td>
</tr>
<tr>
<td>Dielectric Strength, Short Time, 2.03 mm (0.080 in)</td>
<td>D149</td>
<td>kV/mm (V/mil)</td>
<td>24 (600)</td>
<td>24 (600)</td>
</tr>
<tr>
<td>Surface Arc-Resistance</td>
<td>D495</td>
<td>sec</td>
<td>&gt;300</td>
<td>&gt;300</td>
</tr>
<tr>
<td>Volume Resistivity</td>
<td>D257</td>
<td>ohm·cm</td>
<td>&gt;10¹⁸</td>
<td>&gt;10¹⁸</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td>D257</td>
<td>ohm·sq</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>Dissipation Factor, 80 to 2 x 10⁸ Hz</td>
<td>D150</td>
<td></td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Water Absorption, 24 hr</td>
<td>D570</td>
<td>%</td>
<td>&lt;0.0001</td>
<td>—</td>
</tr>
<tr>
<td>UL 94 Flame Rating</td>
<td></td>
<td></td>
<td></td>
<td>94 V-0</td>
</tr>
<tr>
<td>Resistance to Weathering</td>
<td></td>
<td></td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td>Static Coefficient of Friction</td>
<td></td>
<td></td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>Against Polished Steel</td>
<td></td>
<td></td>
<td></td>
<td>0.05–0.08</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>D4894/4895</td>
<td></td>
<td>2.16</td>
<td>2.1–2.3</td>
</tr>
</tbody>
</table>

*aDoes not track
*bThese numerical flame spread ratings are not intended to reflect hazards presented by this or any other material under actual fire conditions.
*cVarious methods used
Teflon™ PTFE fluoropolymer resins are fabricated to form parts by a number of techniques, including ram extrusion, screw extrusion, compression molding, and paste extrusion with an extrusion aid. Although different, these techniques have three basic steps in common: cold forming, sintering, and cooling. These fabricating steps refer to operations that involve, respectively: compacting molding powder to shape by pressing, bonding adjacent surfaces of particles by heating, and controlling crystallinity content of the article by cooling.

Previous work has pointed out that about 15 mechanical properties plus several electrical and chemical properties of Teflon™ PTFE fluoropolymer resins are influenced by molding and sintering conditions. Most notably affected are flex life, permeability, stiffness, resiliency, and impact strength. The five basic factors that influence these end-product properties are:

- **Presence of Macroscopic Flaws**—Internal bubbles, tears, foreign impurities, shear planes, or poor charge-to-charge bonds.
- **Extent of Microporosity**—Number and size of microscopically visible voids created by imperfect particle fusion.
- **Percent Crystallinity**—A percentage based on the weight fraction of a sample consisting of polymer chains fitted in a close-packed, ordered arrangement.
- **Molecular Weight**—A measure of the average length of polymer chains.
- **Degree of Orientation**—A measure of the extent of alignment of polymer chains in a given direction.

While, ideally, a quality control system should be based on direct measurements of these basic factors, simple and direct measuring methods suitable for routine use are not usually available. Instead, a number of highly sensitive, indirect tests have been devised. They are based on measurement of dielectric strength, tensile strength, ultimate elongation, specific gravity, and heat of fusion. Simple, applicable to a variety of shapes, reproducible, and sensitive, the tests and their relation to the five basic quality factors are explained in the following text.

### Dielectric Strength

Dielectric strength is a function of the degree of microporosity. Table 3 shows that it correlates well with size and number of microvoids visible with a microscope. On the other hand, dielectric strength is independent of molecular weight and crystallinity.

#### Table 3. Teflon™ PTFE Granular Resin: Relation of Dielectric Strength to Degree of Microporosity

<table>
<thead>
<tr>
<th>Sample</th>
<th>Appearance of Cross-Section in Microscope</th>
<th>Dielectric Strength, V/mil*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No visible voids at 100x magnification</td>
<td>760</td>
</tr>
<tr>
<td>B</td>
<td>Scattered 0.001-in voids between particles</td>
<td>575</td>
</tr>
<tr>
<td>C</td>
<td>Scattered 0.005-in voids</td>
<td>445</td>
</tr>
<tr>
<td>D</td>
<td>Numerous 0.005-in voids</td>
<td>250</td>
</tr>
</tbody>
</table>

* 1/16-in sheets immersed in A-80 transformer oil per ASTM D149

#### Tensile Strength and Ultimate Elongation

Tensile strength and ultimate elongation depend to some degree on all five quality factors. Table 4, for example, points out the effect of microvoids on the samples described in Table 3. Limited data indicate that this reduction of tensile properties by microvoids is influenced to some extent by crystallinity. While definite evidence indicates that tensile strength falls with rise of percent crystallinity, ultimate elongation increases at first and then drops. Microvoids have their greatest effect in low-crystallinity products.

#### Table 4. Teflon™ PTFE Granular Resin: Effect of Microporosity on Tensile Strength and Elongation

<table>
<thead>
<tr>
<th>Sample</th>
<th>Extent of Microporosity</th>
<th>Tensile Strength, MPa (psi)</th>
<th>Ultimate Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Negligible</td>
<td>24.8 (3,600)</td>
<td>390</td>
</tr>
<tr>
<td>B</td>
<td>Slight</td>
<td>17.4 (2,520)</td>
<td>350</td>
</tr>
<tr>
<td>C</td>
<td>Moderate</td>
<td>13.9 (2,020)</td>
<td>300</td>
</tr>
<tr>
<td>D</td>
<td>Severe</td>
<td>12.4 (1,800)</td>
<td>170</td>
</tr>
</tbody>
</table>

* Free-cooled 1/16-in specimens with relative crystallinity of 65–68% tested by ASTM D4894/4895
Specific Gravity

Specific gravity can be readily measured by water-displacement and gradient-tube techniques, such as those described in ASTM D792 and D1505. These tests do not necessarily give the inherent or precise specific gravity, however, because microvoids introduce a disparity between the measured and the inherent specific gravity. In effect, the displaced water, from which the measured value is derived, accounts for both the resin sample and its contained voids. The void content, as described later on, although not easy to determine, should be known or accounted for in the following manner:

\[
\text{Measured S.G.} = \text{Inherent S.G.} - \left(\text{Inherent S.G.} \times 0.01 \times \% \text{ Void Content}\right)
\]

Without this correction, such as shown in the lower portion of the equation, the precise conversion of the inherent specific gravity to percent crystallinity as shown in Figure 1 will be in error by the amount shown in the two lines representing, by way of example, two arbitrarily chosen void levels, namely 0.5 and 1%.

Table 5 indicates the relative effect of three of the basic factors on a number of properties, many of which depend upon the level of crystallinity. Relatively few properties depend directly upon molecular weight. However, crystallization rates, and, therefore, final levels of crystallinity, do depend upon molecular weight. Molecular weight thus exerts its greatest influence on properties through crystallinity.

To supplement standard quality control methods, a number of laboratory techniques have been developed to check directly the presence of macroflaws, extent of microporosity, percent crystallinity, and molecular weight. Because of their complexity, these methods are not ordinarily suited to routine product testing. As research tools, however, they do aid interpretation of reasons for quality variations.

Macroscopic Flaws

For detection of macroscopic flaws, X-ray radiographic examinations may be employed. Sufficient views are taken to give complete coverage of the piece. In parts more than 2 in thick, at least two views, 90° apart, are required. ASTM method E94 is a useful guide in establishing testing procedures.

### Table 5. Effect on Teflon® PTFE Fluoropolymer Resin Properties Caused by Change in Basic Factor

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Increasing Molecular Weight</th>
<th>Increasing Crystallinity</th>
<th>Increasing Void Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flex Fatigue Life</td>
<td>+100 fold</td>
<td>-100 fold</td>
<td>-1,000 fold</td>
</tr>
<tr>
<td>Compressive Stress at 1% Deformation</td>
<td>0</td>
<td>+50%</td>
<td>0</td>
</tr>
<tr>
<td>Compressibility</td>
<td>0</td>
<td>-50%</td>
<td>—</td>
</tr>
<tr>
<td>Recovery</td>
<td>0</td>
<td>-70%</td>
<td>—</td>
</tr>
<tr>
<td>Permeability to Carbon Dioxide</td>
<td>0</td>
<td>-30%</td>
<td>+1,000 fold</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>0</td>
<td>+5 fold</td>
<td>-30%</td>
</tr>
<tr>
<td>Hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durometer</td>
<td>0</td>
<td>+20%</td>
<td>—</td>
</tr>
<tr>
<td>Rockwell</td>
<td>0</td>
<td>-20%</td>
<td>-30%</td>
</tr>
<tr>
<td>Scleroscope</td>
<td>0</td>
<td>-70%</td>
<td>-10%</td>
</tr>
<tr>
<td>Tensile Impact Strength</td>
<td>0</td>
<td>-15 fold</td>
<td>-80%</td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td>0</td>
<td>0</td>
<td>-70%</td>
</tr>
<tr>
<td>Proportional Limit</td>
<td>0</td>
<td>+80%</td>
<td>-20%</td>
</tr>
<tr>
<td>Yield Stress</td>
<td>0</td>
<td>+15%</td>
<td>-20%</td>
</tr>
<tr>
<td>Yield Strain</td>
<td>0</td>
<td>-15 fold</td>
<td>0</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>+25%</td>
<td>-50%</td>
<td>-50%</td>
</tr>
<tr>
<td>Ultimate Strength</td>
<td>+50%</td>
<td>-70%</td>
<td>-50%</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td>-20%</td>
<td>+100%*</td>
<td>-30%</td>
</tr>
</tbody>
</table>

*Reaches a maximum at 85% crystallinity
Microscopic Voids

While X-ray radiographic methods are satisfactory for detecting macroscopic flaws, they are not sensitive enough for detection of microscopic voids. There are, however, a number of methods developed specifically for this purpose, as discussed below.

Visual Inspection

Visual inspection by a trained observer without a microscope can be of real value in detecting excessive microporosity and other gross quality defects. While it is difficult to convey in words the experience that enables one to judge varying degrees of microporosity, some worthwhile hints are:

- Prepare a comparison series of samples having varying degrees of microporosity. It is best to collect samples that have been processed by the same sintering and cooling conditions. These will have the same inherent specific gravity.
- It is easier to inspect for porosity by transmitted, rather than reflected, light.
- Use a powerful light source directly behind the sample. A large illuminated panel with a ground-glass surface is best for inspecting sheet stock.
- Small cracks are often more readily seen by viewing at an angle of 45°.
- If permissible, cut off a thin section with a sharp knife and inspect it.

Dye Penetrants

Vividly colored penetrants are valuable as an aid in detecting microporosity or gross defects when:

- The part to be tested is less than 1/2-in thick.
- Comparison standards of both acceptable and nonacceptable quality are available.

Both end user and fabricator should agree on the significance of occasional structural flaws, such as edge cracks and adhered flakes of resin or saw marks.

Specific Gravity Comparisons

As has been previously discussed, void content provides a measure of degree of microporosity. It follows, then, that void content* can be defined by rearrangement of the specific gravity equation, as follows:

\[
\text{% Void Content} = \left( \frac{\text{Inherent S.G.} - \text{Measured S.G.}}{\text{Inherent S.G.}} \right) \times 100
\]

A number of techniques have been investigated for determining data for this equation. These methods include: torsional damping (torsion pendulum), infrared spectroscopy, ultrasonics, rebound resiliency, and X-ray diffraction. Infrared and torsional damping techniques appear to be the most sensitive methods.

While it is beyond the scope of this article to cover the details and theory behind these two methods, their comparative precision and limitations can be pointed out. Inherent specific gravity based on an average of two infrared determinations is usually precise within ±0.003 specific gravity units (95% confidence limits). Inherent specific gravity for an average of two torsion pendulum determinations is usually precise to within ±0.002 specific gravity units.

While the torsion pendulum gives slightly better reproducibility than the infrared method, it is considerably less versatile because it requires a fixed-size specimen. However, its cost is considerably less than that of a suitable spectrometer.

With both methods, degree of orientation introduces errors. Because means of correcting these errors are currently unknown, inherent specific gravity of paste-extruded wire coatings, tubing, film, and coined sheeting cannot yet be accurately measured. With paste-extruded products, however, apparent specific gravity measurements may be used to estimate degree of crystallinity because void contents are normally low.

Crystallinity and Molecular Weight

Degree of crystallinity is controlled by molecular weight and the length of time during fabrication that a part is maintained within the temperature range for rapid crystallization (307–327 °C [585–620 °F]). By reheating fabricated parts according to a standard thermal cycle (ASTM D4894/4895), relative molecular weights may be estimated through crystallinity or inherent specific gravity measurements. In parts with low void contents, relative molecular weights may be approximated from apparent specific gravity measurements.

Practical Crystallinity Limits

Technical papers have discussed at length the influence of degree of crystallinity and voids on properties of parts fabricated from Teflon® PTFE fluoropolymer resins. A number of questions have arisen, however, pointing to the need for further clarification of normal limits for these basic variables. While, theoretically, fabricators can control percent crystallinity or inherent specific gravity over wide ranges, there are certain practical limits.
For instance, in parts thicker than 1/4 in, it is not practical for fabricators to cool the interior fast enough to reduce crystallinity below about 55%. Even in thin films rapidly cooled in water, it is difficult to reduce crystallinity below about 46% (inherent specific gravity 2.135). An important point to keep in mind, then, is that measured specific gravities below 2.135 generally reflect some voids in any specimen.

Often, it is also impractical for fabricators to obtain high crystallinity levels, because certain parts must be cooled against cold metal surfaces to obtain close tolerances.

How to Specify Typical Fabricated Parts

When setting property and tolerance specifications, the needs of the application must be balanced against the capabilities of both resin and method of fabrication. If needs are considered and designs frozen before any suppliers of fabricated parts are consulted, confusion, inefficiency, and often unnecessary costs may result.

As an aid in tailoring specifications to wed design needs with capabilities of fabricated parts of Teflon™ PTFE fluoropolymer resins, the following suggestions are offered:

- At the inception of a design program, engineers should acquaint themselves with the properties of Teflon™ PTFE fluoropolymer resins as given in texts such as the Modern Plastics Encyclopedia.
- As soon as the preliminary design is on paper, mechanical properties and dimensions for the application should be reviewed. A number of articles on designing have appeared in the literature and may be consulted.10

Also at this point, competent suppliers of fabricated parts should be consulted. Usually, there are several quality grades of a given fabricated form. By having a supplier point out what is available at an early stage, it is often possible to adjust design to accommodate most economic usage of materials.

Once design is frozen, there are several routes toward setting specifications. In many cases, suitable specifications are already available from such sources as ASTM, SAE, SPI, NIST, and MIL.

In special situations, the previously cited specification sources may not be satisfactory. In such instances, the following guides on test methods may be useful.

Suggested Test Methods for Various Shapes

Table 6 summarizes specific tests for quality checks on extruded rod, molded sheet, molded parts, and tapes or films made from Teflon™ PTFE fluoropolymer resins. The significance of most of these tests has already been discussed.

In the case of extruded rod, tensile strength and ultimate elongation are standard methods for quantitatively determining the strength of charge-to-charge bonds. There are also three qualitative methods sometimes used for the purpose: X-ray radiographic inspection (previously discussed), mandrel bend tests for rods smaller than 1 in, and resintering.

In the latter, an unconfined section of rod is resintered at 371–382 °C (700–720 °F) for a period of 1–4 hr, depending on rod diameter. Extruded rods with poor charge-to-charge bonds develop distinctly visible cracks as a result of this heat-aging cycle.

With extruded rods, determination of dielectric strength and measured specific gravity may be used to check for excessive microporosity.

For testing sheet, dielectric strength and dye penetrant methods give an indication of microporosity. Measured specific gravities also relate to microporosity. The usual purpose of measured specific gravity determinations, however, is to provide an approximate indication of the sheet’s percent crystallinity. Tensile strength and elongation are indicative of overall quality.

With molded parts, X-ray and dye penetrant methods are suggested for detection of surface and internal flaws. Measured specific gravities detect variations in degree of microporosity and percent crystallinity; although again, these effects are not separated in this test. Dimensional stability at elevated temperatures is usually checked by measurements after annealing a part at 288 °C (550 °F).

For films and tapes, pinhole counts and dielectric strength indicate degree of microporosity and incidence of localized flaws. Measured specific gravity is used as an index of percent crystallinity. Tensile measurements, as in the case of sheeting, are used as an all-around index of quality.
Table 6. Teflon™ PTFE Fluoropolymer Resins: ASTM Tests Applicable to Fabricated Parts

<table>
<thead>
<tr>
<th>Property</th>
<th>Extruded Rod</th>
<th>Molded Sheet</th>
<th>Molded Parts</th>
<th>Films and Tapes</th>
<th>Extruded Tubing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>D1710</td>
<td>D3293</td>
<td>D3294</td>
<td>D3308</td>
<td>D3295</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D3369</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td>D1710</td>
<td>D3293</td>
<td>D3294</td>
<td>D3308</td>
<td>D3295</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D3369</td>
</tr>
<tr>
<td>Measured Specific Gravity</td>
<td>D1710</td>
<td>D3293</td>
<td>D3294</td>
<td>D3308</td>
<td>D3295</td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td>D1710</td>
<td>D3293</td>
<td>D3294</td>
<td>D3308</td>
<td>D3295</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D3369</td>
</tr>
<tr>
<td>X-Ray</td>
<td>D1710</td>
<td></td>
<td></td>
<td>D3294</td>
<td></td>
</tr>
<tr>
<td>Melting Point</td>
<td>D4894</td>
<td>D3293</td>
<td>D3294</td>
<td>D3308</td>
<td>D3295</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D3369</td>
</tr>
<tr>
<td>Dye Penetrant</td>
<td>—</td>
<td>D3293</td>
<td>D3294</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Dimensional Stability</td>
<td>D1710</td>
<td>D3293</td>
<td>D3294</td>
<td>—</td>
<td>D3295</td>
</tr>
<tr>
<td>Pinhole Count</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>D3308</td>
</tr>
</tbody>
</table>

Figure 1. Relation of Percent Crystallinity to Specific Gravity
Strength and Stiffness

General Characteristics

Fabricated shapes of Teflon® PTFE fluoropolymer resins are tough, flexible in thin sections, and fairly rigid in thick sections. Useful but varying mechanical properties are maintained from -268 to 260 °C (-450 to 500 °F) for Teflon® PTFE fluoropolymer resins. Surfaces of fabricated parts have an extremely low coefficient of friction. Almost nothing sticks to them. However, specially treated surfaces will accept conventional industrial adhesives. Teflon® PTFE fluoropolymer resins are almost completely inert to chemical attack, but, under special conditions, are affected by such substances as alkali metals and halogens. Low-loss electrical characteristics remain essentially constant, regardless of frequency, over a wide temperature range.

Teflon® PTFE fluoropolymer resins tend to be opaque, crystalline, and malleable.

Teflon® PTFE fluoropolymer resins can be aggregated into dense, coherent shapes at normal temperatures by various “preforming techniques,” which apply uniform pressure to the unheated Teflon® PTFE fluoropolymer resin. Preformed products are strengthened by heating above 327 °C (620 °F), generally 371–382 °C (700–720 °F), until the resin particles coalesce, and then cooling below 327 °C (620 °F). Products sintered in this manner may be further shaped by various post-forming techniques that are preformed most readily at temperatures approaching but below the 327 °C (620 °F) transition temperature. Because Teflon® PTFE fluoropolymer resins enter into a gel state at 327 °C (621 °F), which is not conducive to melt flow, preforming, sintering, and post-forming are the processing techniques most commonly used.

Design Considerations

Parts to be made of Teflon® PTFE fluoropolymer resins may be designed in exactly the same manner as parts made of other materials, such as steel, brass, lead, concrete, etc. Even the same formulas may be used if careful attention is paid to special characteristics of the resin. A Teflon® PTFE fluoropolymer resin may be chosen in preference to other materials because of its better chemical resistance, heat resistance, friction coefficient, dielectric strength, toughness, weather resistance, or combination of such properties. Most materials are affected to some extent by temperature, moisture, and environment. Because Teflon® PTFE fluoropolymer resins exhibit zero moisture absorption and are unaffected by almost all environmental conditions, designers will be interested mainly in property changes resulting from temperature variation.

When load is applied over a period of time, creep and cold flow must be considered. Consequently, data are presented for long-term loading as well as short-term loading. Information for the tables and charts was obtained from samples described in Table 7. These samples are representative of commercially available moldings.

Strength and Stiffness

Teflon® PTFE fluoropolymer resins are engineering materials whose performance in any particular application may be predicted by calculation in the same manner as for other engineering materials. However, just as properties of woods are different from those of metals, the properties of Teflon® PTFE fluoropolymer resins are different from those of other engineering materials. From the following data, strength and stiffness values can be selected that, with appropriate safety factors, will allow standard engineering formulas to be used in designing parts.

Table 7. Teflon® PTFE Granular Resin: Description of Samples Used in Tests

<table>
<thead>
<tr>
<th>Fabricated Form</th>
<th>Average Specific Gravity</th>
<th>Void Content</th>
<th>Crystallinity</th>
<th>Preform Pressure, MPa (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rod, 6 in long x 0.6 in diameter (molded)</td>
<td>2.17</td>
<td>&lt;0.3%</td>
<td>60% ± 2%</td>
<td>17.2 (2,500)</td>
</tr>
<tr>
<td>Sheet, 14 in x 14 in, 1/8 in and 1/16 in thick</td>
<td>2.17</td>
<td>&lt;0.3%</td>
<td>60% ± 2%</td>
<td>17.2 (2,500)</td>
</tr>
</tbody>
</table>
Tensile Stress

Stress-strain curves for temperatures in the usual design range (see Figure 2a) show that yield occurs at high deformations. Elastic response begins to deviate from linearity at strains of only a few percent, as with most plastics. Therefore, in designing with Teflon™ PTFE fluoropolymer resins, it is often best to work with acceptable strain and determine the corresponding stress. Curves that show ultimate tensile strength, the point at which fracture occurs, are given in Figure 2b.

Figure 3 shows strain at corresponding stresses for various temperatures. The percent strain selected for design calculations should take into account the highest temperature at which the part will operate. Because it is not always possible to work with an acceptable strain, Table 8 gives the yield strength as a function of temperature.

Compressive Stress

Compression and strain are indicated at three temperatures for Teflon™ PTFE fluoropolymer resins (see Figure 4). Stress-strain curves for compression are similar to those for tension at low values of strain (see Figure 5). However, as strain increases, the curves become less similar. Yield points for compression and tension occur at about the same stress values. For compression, the lower strains at higher stress may be a result of analyzing test data on the basis of original cross-sections.

Shear Stress

Figure 6 is a plot of shear stress against shear strain. In a part subject to shear, a specified strain should be selected and the corresponding stress used for design calculations as mentioned previously.

Poisson’s Ratio

Poisson’s ratio is 0.46 at 23 °C (73 °F) and approaches a limiting value of 0.50 with increasing temperature.

Modulus of Elasticity

No attempt has been made to include data on modulus of elasticity. Because modulus of elasticity $E$ is

$$E = \frac{\text{Stress (psi)}}{\text{Strain (in/in)}}$$

the preceding stress-strain curves permit substitution, when working at a specified strain, of the corresponding stress so that modulus of elasticity can be determined.

<table>
<thead>
<tr>
<th>Temperature, °C (°F)</th>
<th>Teflon™ PTFE Yield Strength, MPa (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>–251 (–420)</td>
<td>131 (19,000)</td>
</tr>
<tr>
<td>–196 (–320)</td>
<td>110 (16,000)</td>
</tr>
<tr>
<td>–129 (–200)</td>
<td>79.3 (11,500)</td>
</tr>
<tr>
<td>–73 (–100)</td>
<td>53.1 (7,700)</td>
</tr>
<tr>
<td>–56 (–68)</td>
<td>26.2 (3,800)</td>
</tr>
<tr>
<td>0 (32)</td>
<td>12.4 (1,800)</td>
</tr>
<tr>
<td>23 (73)</td>
<td>9.0 (1,300)</td>
</tr>
<tr>
<td>70 (158)</td>
<td>5.5 (800)</td>
</tr>
<tr>
<td>121 (250)</td>
<td>3.4 (500)</td>
</tr>
</tbody>
</table>
Figure 2a. Tensile Stress, Based on Original Cross-Section
Figure 2b. Stress versus Strain in Tension

-56 °C (-69 °F)

23 °C (73 °F)

204 °C (400 °F)

260 °C (500 °F)
Figure 3. Tensile Stress versus Temperature at Constant Strain
Figure 4. Stress versus Strain in Compression (ASTM D695)
Figure 5. Stress versus Strain in Tension and Compression (ASTM D695)

![Graph of Stress versus Strain in Tension and Compression](image_url)

- **Tension**
  - 23 °C (73 °F): 27.6 MPa
  - 100 °C (212 °F): 20.7 MPa
  - 204 °C (400 °F): 13.8 MPa

- **Compression**
  - 23 °C (73 °F): -27.6 MPa
  - 100 °C (212 °F): -20.7 MPa
  - 204 °C (400 °F): -13.8 MPa

**Stress, psi**

-4000 -3000 -2000 -1000 0 1000 2000 3000 4000

**Stress, MPa**

-27.6 -20.7 -13.8 -6.9 0 6.9 13.8 20.7 27.6

**Strain, %**

-30 -20 -10 0 10 20 30
Figure 6. Stress versus Strain in Shear to 20%
Creep and Cold Flow
A plastic material subjected to continuous load experiences a continued deformation with time that is called creep or cold flow. A similar phenomenon occurs with metals at elevated temperatures. With most plastics, however, deformation can be significant even at room temperature or below; thus, the name “cold flow.”

Creep is the total deformation under stress after a specified time in a given environment beyond that instantaneous strain that occurs immediately upon loading. Independent variables that affect creep are time under load, temperature, and load or stress level.

Initial strain or deformation occurs instantaneously as a load is applied to Teflon™ PTFE fluoropolymer resins. Following this initial strain is a period during which the part continues to deform but at a decreasing rate. Creep data over a wide range of temperatures are plotted for tensile loading in Figures 7a through 7d, for compressive loading in Figures 8a and 8b, and for torsional loading in Figures 9a and 9b.

Apparent Modulus of Elasticity
The concept of “apparent modulus” is a convenient method for expressing creep because it takes into account initial strain for an applied stress plus the amount of deformation or strain that occurs with time. Thus, apparent modulus $E_A$ is

$$E_A = \frac{\text{Stress (psi)}}{\text{Initial Strain + Creep}}$$

Because parts tend to deform in time at a decreasing rate, the acceptable strain based on service life of the part must be determined—the shorter the duration of load, the higher the apparent modulus and the higher the allowable stress. Apparent modulus is most easily explained with an example.

As long as the stress level is below the elastic limit of the material, modulus of elasticity $E$ is obtained from the above equation. For a compressive stress of 1,000 psi, Figure 4 gives a strain of 0.015 in/in for Teflon™ PTFE fluoropolymer resin at 23 °C (73 °F). Then,

$$E = \frac{1,000}{0.015} = 66,700 \text{ psi}$$

If the same stress level prevails for 200 hr, total strain will be the sum of initial strain plus strain due to time. This total strain is obtained from Figure 8a, where total deformation under compressive load for 200 hr is 0.02 in/in for Teflon™ PTFE fluoropolymer resin. Therefore,

$$E_A = \frac{1,000}{0.02} = 50,000 \text{ psi}$$

Similarly, $E_A$ can be determined for 1 yr. Extrapolation of the curve in Figure 8a gives a deformation of 0.025 in/in, and

$$E_A = \frac{1,000}{0.025} = 40,000 \text{ psi}$$

When plotted against time, these calculated values for “apparent” modulus provide an excellent means for predicting creep at various stress levels. For all practical purposes, curves of deformation versus time eventually tend to level off. Beyond a certain point, creep is small and may be neglected for many applications.

Stress Relaxation
When materials that creep or cold flow are used as gaskets in flanged joints, the phenomenon of stress relaxation is generally encountered. In flanged, bolted connections, parts of Teflon™ PTFE fluoropolymer resins will cold flow between the flange faces with a resultant decrease in bolt pressure. Such relaxation in gasket stock may result in a leaky joint. Tightening the flange bolts during the first day after installation will usually maintain bolting pressure and prevent leakage; thereafter, stress relaxation will be negligible.

Typical curves for tensile stress relaxation illustrate the rates at which tensile stress decays when the specimen is maintained at constant strain (see Figures 10a and 10b).

Compressive Recovery
Specimens that were successively compressed and allowed to recover from various percentages of strain indicate that they experience no work hardening. Recovery of the specimen is nearly complete, provided the original strain does not exceed the yield strain.
Recommendation for Gasket Design

To minimize creep and stress relaxation in gaskets, the following rules are recommended:

- Use bolting loads less than 6.9 MPa (1,000 psi) for unconfined gaskets.
- Specify the thinnest possible gasket that will accommodate flange roughness. Gaskets thicker than approximately 1.6 mm (1/16 in) increase the amount and rate of stress relaxation.
- Use reinforced compositions made with Teflon® PTFE fluoropolymer resin, such as 60% Teflon® PTFE fluoropolymer resin and 40% fiber, for temperatures higher than 149 °C (300 °F).
- Design a “self-contained” joint with captive gasket when such construction is desirable.

It is advisable to check the torque on a gasket made from Teflon® PTFE fluoropolymer resins and to re-tighten once, if needed, following the first 24 hr in service.

The three forces that act on a gasket that is bolted securely in position are: bolt load, hydrostatic end force, and internal pressure. The procedure in the ASME Boiler and Pressure Vessel Code, Section VIII, may be used to calculate required bolt loadings for solid gaskets of Teflon® PTFE fluoropolymer resins. The method requires knowledge of the “yield stress” and the “gasket factor.” Yield stress is the stress required to seal the gasket or the minimum stress that will affect a seal against even slight fluid pressure. As internal pressure is applied to the vessel, the flanges tend to separate; thus, lowering the effective stress on the gasket. Obviously, to maintain the seal requires that resultant stress on the gasket exceed the internal pressure. The minimum required ratio of these pressures is called the gasket factor.

Proved values for yield stress and gasket factor are listed in Table 9 for solid Teflon® PTFE fluoropolymer resins. With these values, the necessary gasket load can be calculated from Formula UA-47-2 given in the above ASME reference. Required gasket load can then be converted to bolt load by standard mechanical engineering calculations (see Mechanical Engineers’ Handbook, Marks, Section 3).

Table 9. Values for Calculations of Required Gasket Loads

<table>
<thead>
<tr>
<th>Thickness, mm (in)</th>
<th>Yield Stress, MPa (psi)</th>
<th>Gasket Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 (1/8)</td>
<td>8.3 (1,200)</td>
<td>2.00</td>
</tr>
<tr>
<td>2.4 (3/32)</td>
<td>9.3 (1,350)</td>
<td>2.50</td>
</tr>
<tr>
<td>1.6 (1/16)</td>
<td>11.0 (1,600)</td>
<td>2.75</td>
</tr>
<tr>
<td>0.8 (1/32)</td>
<td>22.1 (3,200)</td>
<td>3.50</td>
</tr>
</tbody>
</table>

Gaskets made by enveloping fillers or rubber in molded Teflon® PTFE fluoropolymer resins are widely used for flanged connections to glass-lined reaction vessels and to glass-lined pipe. Spiral-wound gaskets of stainless steel and sheet stock of Teflon® PTFE fluoropolymer resin have been used successfully in both large and small flanged joints requiring high bolting pressures. Molded Teflon® PTFE fluoropolymer resins, either alone or in combination with other gasket materials, also give excellent service under the most corrosive conditions encountered in the chemical industry.

The performance of Teflon® PTFE fluoropolymer resins is improved considerably by use of fillers. Such modification affects certain mechanical properties and permits resin filler compositions to be tailored to the requirements of a wide variety of mechanical, electrical, and chemical applications.

In general, Teflon® PTFE fluoropolymer resins can be compounded to increase:

- Resistance to initial deformation under load by approximately 25%
- Resistance to rotating shaft wear by as much as 500x
- Stiffness by a factor of two or three
- Thermal conductivity by a factor of five
- Resistance to creep approximately two-fold
- Thermal dimensional stability by a factor of two
- Hardness by approximately 10%

Further, modified compositions retain the desirable properties of uncompounded Teflon® PTFE fluoropolymer resins.
Figure 7a. Total Deformation versus Time Under Load at -54 °C (-65 °F)

- 20.7 MPa (3,000 psi)
- 13.8 MPa (2,000 psi)
- 6.9 MPa (1,000 psi)

Figure 7b. Total Deformation versus Time Under Load at 23 °C (73 °F)

- 10.34 MPa (1,500 psi)
- 6.90 MPa (1,000 psi)
- 3.45 MPa (500 psi)
Figure 7c. Total Deformation versus Time Under Tensile Load at 100 °C (212 °F)

Figure 7d. Total Deformation versus Time Under Tensile Load at 200 °C (392 °F)
Figure 8a. Total Deformation versus Time Under Compressive Load at 23 °C (73 °F)

- 12.1 MPa (1,750 psi)
- 6.9 MPa (1,000 psi)
- 3.4 MPa (500 psi)

Figure 8b. Total Deformation versus Time Under Compressive Load at 100 °C (212 °F)

- 5.2 MPa (750 psi)
- 3.4 MPa (500 psi)
- 1.4 MPa (200 psi)
Figure 9a. Total Deformation versus Time Under Torsional Load at 23 °C (73 °F)

Figure 9b. Total Deformation versus Time Under Torsional Load at 100 °C (212 °F)
**Figure 10a. Tensile Strength Relaxation at 23 °C (73 °F)**

- Stress, psi
- Stress, MPa
- Time, hr

**Figure 10b. Tensile Strength Relaxation at 100 °C (212 °F)**

- Stress, psi
- Stress, MPa
- Time, hr
Effect of Temperature, Fatigue, and Impact

Thermal Expansion

Linear expansion of Teflon™ PTFE fluoropolymer resins is shown in Figure 11 and Table 10. A marked change in volume of 1.0 to 1.8% is evident for Teflon™ PTFE fluoropolymer resins in the transition zone from 18–25 °C (65–77 °F). A part that has been machined on either side of this zone will obviously change dimensions if permitted to go through the zone. Thus, final operating temperature of a precision part must be accurately determined. Measurement on a production basis must allow for this volume change if the transition zone is traversed in either manufacture or operation of the part. Table 11 gives the coefficient of cubical expansion for various temperature ranges.

Low Temperature Properties

Parts fabricated of Teflon™ PTFE fluoropolymer resins exhibit high strength, toughness, and self-lubrication at low temperatures. Teflon™ PTFE fluoropolymer resins are useful from -268 °C (-450 °F) and are highly flexible from -79 °C (-110 °F).

Table 10. Teflon™ PTFE Fluoropolymer Resins Linear Coefficients of Expansion

<table>
<thead>
<tr>
<th>Temperature Range, °C (°F)</th>
<th>Linear Coefficient of Expansion, 10⁻⁵ mm/mm·°C (10⁻⁵ in/in·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 to -190 (77 to -310)</td>
<td>8.6 (4.8)</td>
</tr>
<tr>
<td>25 to -150 (77 to -238)</td>
<td>9.6 (5.3)</td>
</tr>
<tr>
<td>25 to -100 (77 to -148)</td>
<td>11.2 (6.2)</td>
</tr>
<tr>
<td>25 to -50 (77 to -58)</td>
<td>13.5 (7.5)</td>
</tr>
<tr>
<td>25 to 0 (77 to 32)</td>
<td>20 (11.1)</td>
</tr>
<tr>
<td>10 to 20 (50 to 68)</td>
<td>16 (8.9)</td>
</tr>
<tr>
<td>20 to 25 (68 to 77)</td>
<td>79 (43.9)</td>
</tr>
<tr>
<td>25 to 30 (77 to 86)</td>
<td>16 (8.9)</td>
</tr>
<tr>
<td>25 to 50 (77 to 122)</td>
<td>12.4 (6.9)</td>
</tr>
<tr>
<td>25 to 100 (77 to 212)</td>
<td>12.4 (6.9)</td>
</tr>
<tr>
<td>25 to 150 (77 to 302)</td>
<td>13.5 (7.5)</td>
</tr>
<tr>
<td>25 to 200 (77 to 392)</td>
<td>15.1 (8.4)</td>
</tr>
<tr>
<td>25 to 250 (77 to 482)</td>
<td>17.5 (9.7)</td>
</tr>
<tr>
<td>25 to 300 (77 to 572)</td>
<td>22 (12.1)</td>
</tr>
</tbody>
</table>

Table 11. Teflon™ PTFE Fluoropolymer Resins Cubical Coefficients of Expansion

<table>
<thead>
<tr>
<th>Temperature Range, °C (°F)</th>
<th>Cubical Coefficient of Expansion, cm³/cm³·°C (in³/in³·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40 to 15 (-40 to 59)</td>
<td>2.6 x 10⁻⁴ (1.5 x 10⁻⁴)</td>
</tr>
<tr>
<td>15 to 35 (59 to 95)</td>
<td>1.7%*</td>
</tr>
<tr>
<td>35 to 140 (95 to 284)</td>
<td>3.1 x 10⁻⁴ (1.7 x 10⁻⁴)</td>
</tr>
<tr>
<td>140 to 200 (284 to 392)</td>
<td>6.3 x 10⁻⁴ (3.5 x 10⁻⁴)</td>
</tr>
<tr>
<td>200 to 250 (392 to 482)</td>
<td>8.0 x 10⁻⁴ (4.4 x 10⁻⁴)</td>
</tr>
<tr>
<td>250 to 300 (482 to 572)</td>
<td>1.0 x 10⁻³ (5.7 x 10⁻⁴)</td>
</tr>
</tbody>
</table>

* Quinn et al., J. Applied Phys. 22, 1085 (1951)

Thermal Conductivity and Specific Heat

The average thermal conductivity of Teflon™ PTFE fluoropolymer resin is 1.7 ± 0.3 Btu·in/hr·ft²·°F. The average heat capacity is 0.3 Btu/lb·°F for Teflon™ PTFE fluoropolymer resins. These data were obtained at temperatures ranging from 20–260 °C (68–500 °F).

Heat Distortion

Temperatures obtained for heat distortion of Teflon™ PTFE fluoropolymer resins are 122 °C (252 °F) for a stress of 66 psi and 56 °C (132 °F) for a stress of 264 psi (ASTM D648).

Elastic Memory

Parts made from Teflon™ PTFE fluoropolymer resins tend to return to their original dimensions after a deformation, but the process of recovery may require a long time. A fabricated part that creeps or deforms over a period of time under stress will recover its original shape when stress is removed and the part is raised to sintering temperature. However, partial recovery will occur at lower temperatures. At any given temperature, recovery to be expected at that temperature is substantially complete in 15 min or less, but extent of recovery increases with increased temperature.

For example, a filament of Teflon™ PTFE fluoropolymer resin 4 in long, stretched to a length of 1.2 in and heated at 100 °C (212 °F), recovers to approximately 11 in within 15 min and then remains substantially unchanged. A similar piece heated to 200 °C (392 °F) recovers to 10 in. The first piece, after additional heating to 200 °C (392 °F), undergoes further recovery until it is 10 in long. When heated to 350 °C (662 °F), both pieces return to their original length of 4 in.
Figure 11. Linear Thermal Expansion versus Temperature

Table 12. Teflon™ PTFE Fluoropolymer Resins: Decomposition Rates at Elevated Temperatures

<table>
<thead>
<tr>
<th>Resin</th>
<th>Temperature, °C (°F)</th>
<th>Rate of Decomposition, %/hr</th>
<th>Fine Powder</th>
<th>Granular Resin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Initial</td>
</tr>
<tr>
<td>32 (450)</td>
<td>0.0001–0.0002</td>
<td>0.00001–0.00005</td>
<td>1 x 10⁻¹¹</td>
<td></td>
</tr>
<tr>
<td>260 (500)</td>
<td>0.0006</td>
<td>0.0001–0.0002</td>
<td>100 x 10⁻¹¹</td>
<td></td>
</tr>
<tr>
<td>316 (600)</td>
<td>0.005</td>
<td>0.0005</td>
<td>0.00002</td>
<td></td>
</tr>
<tr>
<td>371 (700)</td>
<td>0.03</td>
<td>0.004</td>
<td>0.0009</td>
<td></td>
</tr>
</tbody>
</table>
Decomposition at Elevated Temperatures

Rate of decomposition of a part of Teflon® PTFE fluoroelastomer resin depends on the particular resin, temperature, heat-exposure time, and, to a lesser extent, pressure and nature of the environment. In designs where the rate of outgassing is important, as in high-vacuum work or for safety considerations, initial rates of decomposition in Table 12 may be used. For most applications, these decomposition rates are small enough below the maximum service temperature (260 °C [500 °F] for Teflon® PTFE fluoropolymer resins), that no special precautions are necessary. Where temperatures run above 343 °C (650 °F) during fabrication, proper ventilation is required.

Experience indicates that in many instances the rate of decomposition of an article fabricated from Teflon® PTFE fluoropolymer resin decreases after continual exposure. For example, when parts made of Teflon® PTFE fluoropolymer resin are used, a very low, fairly steady decomposition rate is established after less than 1% of the resins have decomposed.

Impact

Ability to absorb impact energy, or impact toughness, is difficult to predict in a part because shape has a major effect on performance. Understanding how a part resists impact, however, helps in selecting a good design.

The energy of an impact has to be absorbed by a force developed within the part multiplied by the distance the part can deform. Designing flexibility into the part to lengthen the distance over which the energy is absorbed greatly reduces the internal force required to resist the impact. For example, a rigid base made from spring steel would not have as high a capacity for absorbing energy as a coil spring made from the same material. The same factors that affect metals also affect plastics. As more and more flexibility is designed into a part subject to impact load, the better the part will perform.

Teflon® PTFE fluoropolymer resins have excellent impact strength over a wide range of temperatures. Average values for specimens subjected to the tensile and Izod impact tests are given in Table 13.

There is no exact method for relating impact test data to actual design calculations or performance. Generally, in addition to incorporating flexibility, the most important method for obtaining toughness or impact resistance is to eliminate all sharp corners and other features subject to high stress concentration. For exact design, prototype models must be tested under actual loads.

### Table 13. Tensile and Izod Impact Strength

<table>
<thead>
<tr>
<th>Resin</th>
<th>Temperature, °C (°F)</th>
<th>Tensile, ft·lb/in²</th>
<th>Izod, ft·lb/in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teflon® PTFE</td>
<td>23 (73)</td>
<td>320</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>-54 (-65)</td>
<td>105</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*ASTM D256

Hardness and Friction

Hardness

Table 14 lists the hardness of Teflon® PTFE fluoropolymer resins as determined by various tests. Fillers elevate the hardness of Teflon® PTFE fluoropolymer resins by 10 to 15%, and much of the improvement is retained over a wide temperature range. In general, the greater the filler loading, the harder the compound. Spherical or flake fillers impart the best hardness.

### Table 14. Hardness

<table>
<thead>
<tr>
<th>Resin</th>
<th>Rockwell R Scale*11</th>
<th>Durometer D Scale**</th>
<th>Durometer A Scale**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teflon® PTFE</td>
<td>58</td>
<td>52</td>
<td>98</td>
</tr>
</tbody>
</table>

*ASTM D785 or D2240
**23 °C (73 °F)

Friction (Granular)

Teflon® PTFE fluoropolymer resins have a smooth surface with a slippery feel. Because of the low coefficient of friction of Teflon® PTFE fluoropolymer resins (see Table 15), there have been many practical non-lubricated and minimally lubricated mechanical systems developed.
Teflon® PTFE fluoropolymer resins exhibit exceptionally low friction in non-lubricated applications, especially at low surface velocities and pressures higher than 5 psi. The coefficient of friction increases rapidly with sliding speeds up to about 100 ft/min, under all pressure conditions. This pattern of behavior (see Figure 12) prevents “stick-slip” tendencies. Moreover, no “squeaking” or noise occurs, even at the slowest speeds. Above 150 ft/min, sliding velocity has relatively little effect at combinations of pressure and velocity below the composition’s PV limit. Figure 13 indicates that static friction of Teflon® PTFE fluoropolymer resins decreases with increases in pressure.

PV limits presented in Table 16 define the maximum combinations of pressure and velocity at which these materials will operate continuously without lubrication. They are based on operation in air at ambient temperatures of 21–27 °C (70–80 °F). The PV limits of all Teflon® PTFE fluoropolymer resin matrix compositions approach zero at 288–315 °C (550–600 °F) ambient temperature. In other words, the limiting surface temperature for operation of Teflon® PTFE fluoropolymer resin compositions is 288–315 °C (550–600 °F), regardless of the cause of the temperature. Reduced ambient temperatures, below 21 °C (70 °F), and/or cooling will provide increased PV limits.

PV limit does not necessarily define useful combinations of pressure and velocity because wear is not considered in its determination. The useful PV limit of a material cannot exceed the PV limit and must take into account the composition’s wear characteristics and allowable wear for the application.

Wear factor, K, is a proportionality factor relating to the wear of a non-lubricated surface (operating against a specific mating surface at combinations of pressure and velocity below the material’s PV limit). The wear factors listed in Table 16 can be used to predict wear against specific mating surfaces, using the following expression:

\[ t = KPVT \]

where \( t \) = Wear, in
\( K \) = Wear factor, \( \frac{\text{in}^3\cdot\text{min}}{\text{lb} \cdot \text{ft} \cdot \text{hr}} \)
\( P \) = Pressure, psi
\( V \) = Velocity, fpm
\( T \) = Time, hr

**Table 15. Coefficient of Friction**

<table>
<thead>
<tr>
<th>Property</th>
<th>Teflon® PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Load, 500 psi</td>
<td>0.05–0.08</td>
</tr>
<tr>
<td>Dynamic PV, 8,000 to 10,000, at 10 fpm</td>
<td>0.10</td>
</tr>
<tr>
<td>Dynamic PV, 8,000 to 10,000, at 100 fpm</td>
<td>0.13</td>
</tr>
<tr>
<td>Dynamic PV, 8,000 to 10,000, at 1,000 fpm</td>
<td>Unstable Operation</td>
</tr>
</tbody>
</table>

**Table 16. PV and Wear Performance**

<table>
<thead>
<tr>
<th>Property</th>
<th>Teflon® PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Limit (lb/in² x fpm) at 10 fpm*</td>
<td>1,200</td>
</tr>
<tr>
<td>PV Limit (lb/in² x fpm) at 100 fpm*</td>
<td>1,800</td>
</tr>
<tr>
<td>PV Limit (lb/in² x fpm) at 1,000 fpm*</td>
<td>2,500</td>
</tr>
<tr>
<td>PV for 0.005 in radial wear in 1,000 hr**</td>
<td>20</td>
</tr>
<tr>
<td>Wear Factor, K (x 10⁻¹⁰) (in³·min/ft·lb·hr)**</td>
<td>2,500</td>
</tr>
</tbody>
</table>

*Ambient temperature 21–27 °C (70–80 °F)
**Based on (1) unidirectional load on fixed bushing or (2) thrust washer
***At PV values below the composition’s PV limit when operating unlubricated against soft carbon steels (RC20 to 25) finished to 12–20 µin (AA). Factor is also applicable for operation against most stainless steels and cast irons.

**Abrasion and Wear (Granular)**

Parts fabricated from Teflon® PTFE fluoropolymer resins have good wear properties as previously shown in Table 16. Tables 17, 18, and 19 indicate the abrasion resistance of unfilled fluoropolymer resins for various types of tests. These three tests do not represent typical bearing wear because, in each, a new abrading surface is being continuously presented versus a repeating surface.
Figure 12. Coefficient of Friction versus Sliding Speed

Temperature Range: 24–66 °C (75–150 °F)

- 0.345–3.45 kPa (0.05–0.5 psi)
- 9.65 kPa (1.4 psi)
- 345–517 kPa (50–75 psi)

Figure 13. Coefficient of Friction versus Load (at <2 ft/min and room temperature)

- Up to 0.0002 psi
- 0.05 to 0.5 psi
- 0.002 to 0.2 psi
- 1.4 psi
- 0.22 to 2.2 psi
- 50 to 75 psi
- 400 to 3,600 psi

Load, lb: 0, 500, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, 4,000
Teflon™ PTFE Fluoropolymer Resins

Electrical Properties

Teflon™ PTFE fluoropolymer resins offer remarkable electrical stability over a wide range of frequency and environmental conditions. In this respect, they differ markedly from other insulating materials.

Dielectric Constant

The dielectric constant of Teflon™ PTFE fluoropolymer resins shows less change over a wide range of temperatures and frequencies than any other solid material. This value remains essentially constant at 2.1 over the entire frequency spectrum.

Teflon™ PTFE fluoropolymer resin specimens have been heat-aged at 300 °C (572 °F) for six months, and then cooled to room temperature for measurement, with no change in dielectric constant. Non-fluoropolymer insulating materials do not show these properties.

Dissipation Factor

The dissipation factor of Teflon™ PTFE fluoropolymer resins remains below 0.0004 over a frequency range up to 10^8 Hz.

The dissipation factor of Teflon™ PTFE fluoropolymer resins remains quite constant. For Teflon™ PTFE fluoropolymer resins at room temperature, it reaches a peak at about 10^9 Hz. This peak value is 0.0004 for Teflon™ PTFE fluoropolymer resins. Theoretical analysis of this phenomenon and spot checks indicate that as temperature increases, the peak will occur at higher frequencies.

Dielectric Strength

The dielectric strength of Teflon™ PTFE fluoropolymer resins is high and does not vary with temperature and thermal aging. Initial dielectric strength is very high (600 V/mil for 1.5 mm [0.06 in] thickness) as measured by the ASTM short-time test. As with any material, the value drops as thickness of specimen increases.

Life at high dielectric stresses is dependent on corona discharge. The absence of corona, as in special wire constructions, permits very high voltage stress without damage to Teflon™ PTFE fluoropolymer resins. Changes in relative humidity or physical stress imposed upon the material do not diminish life at these voltage stresses.
Surface Arc-Resistance

Surface arc-resistance of Teflon® PTFE fluoropolymer resins is high and not affected by heat-aging. When Teflon® PTFE fluoropolymer resins are subjected to a surface arc in air, they do not track or form a carbonized conducting path. When tested by the procedure of ASTM D495, Teflon® PTFE fluoropolymer resins pass the maximum time of 300 sec without failure.

The unique nonstick surface of these resins helps reduce surface arc phenomena in two ways:

- It helps prevent formation of surface contamination; thereby, reducing the possibility of arcing.
- If an arc is produced, the discharge frequently cleans the surface of the resin—increasing the time before another arc.

Volume and Surface Resistivity

Volume resistivity (>10¹⁸ ohm·cm) and surface resistivity (>10¹⁶ ohm·sq) for Teflon® PTFE fluoropolymer resins are at the top of the measurable range. Neither resistivity is affected by heat-aging or temperatures up to recommended service limits.

Other Properties

Weathering

Parts fabricated of Teflon® PTFE fluoropolymer resins are virtually unaffected by weather. Conclusive tests on samples exposed for 15 yr to practically all climatic conditions confirm these weather-resistant properties. Thus, where applications demand the ultimate in dependability under these conditions, these resins are the answer. Resistance to extreme heat, cold, and ultraviolet light encountered in radar and other electronic components, such as antenna bushings, are excellent examples of the value of this material to the industrial designer.

Miscellaneous

Molded Teflon® PTFE fluoropolymer resins have excellent vibration dampening properties, both at sonic and ultrasonic frequencies. Installations for this purpose have been very successful. The thickness of material required must be sufficient to absorb the energy produced and is usually determined experimentally.

Chemical Properties

Resistance to Chemical Attack

Teflon® PTFE fluoropolymer resins are essentially chemically inert. Up to the upper use temperature (260 ºC [500 ºF]) for Teflon® PTFE fluoropolymer resins, only very few chemicals are known to chemically react with these resins, i.e., molten alkali metals, turbulent liquid, or gaseous fluorine, and a few fluorochemicals, such as chlorine trifluoride, CIF₃, or oxygen difluoride, OF₂, which readily liberate free fluorine at elevated temperatures.

The unique degree of inertness of Teflon® PTFE fluoropolymer resins reflects their chemical structure. Molecules of Teflon® PTFE fluoropolymer resins are formed simply from strong carbon-carbon and super-strong carbon-fluorine interatomic bonds; moreover, the fluorine atoms form a protective sheath around the carbon core of each molecule. This structure also produces other special properties, such as insolubility and low-surface adherability and friction.

To a minor degree, halogenated organic chemicals may be absorbed by fluoropolymer resins. This will cause a very small weight change and, in some cases, slight swelling. If absorption is very high, it usually indicates a fabricated part of high porosity.

Permeability

Fluoropolymer resins may be permeated to a limited extent by some substances. Permeation rates are generally comparable to those observed for other thermoplastics.

For more detailed data on exposure of Teflon® PTFE fluoropolymer resins to chemical media, please contact your Chemours representative.

Forming and Fabrication

When extreme tolerance must be specified, or when product shapes are very complex, or when just one or two prototypes are required, the machining of Teflon® PTFE fluoropolymer resins becomes a logical means of fabrication.

All standard operations—turning, facing, boring, drilling, threading, tapping, reaming, grinding, etc.—are applicable to Teflon® PTFE fluoropolymer resins. Special machinery is not necessary.

When machining parts from Teflon® PTFE fluoropolymer resins, either manually or automatically, the basic rule to remember is that these resins possess physical
properties unlike those of any other commonly machined material. They are soft, yet springy. They are waxy, yet tough. They have the cutting “feel” of brass, yet the tool-wear effect of stainless steel. Nevertheless, any trained machinist can readily shape Teflon™ PTFE fluoropolymer resins to tolerances of ±0.001 in and, with special care, to ±0.0005 in.

**Choose Correct Working Speeds**

One property of Teflon™ PTFE fluoropolymer resins strongly influencing machining techniques is their exceptionally low thermal conductivity. They do not rapidly absorb and dissipate heat generated at a cutting edge. If too much generated heat is retained in the cutting zone, it will tend to dull the tool and overheat the resin. Coolants, then, are desirable during machining operations, particularly above a surface speed of 150 m/min (500 fpm).

Coupled with low conductivity, the high thermal expansion of Teflon™ PTFE fluoropolymer resins (nearly 10x that of metals) could pose supplemental problems. Any generation and localization of excess heat will cause expansion of the fluoropolymer material at that point. Depending on the thickness of the section and the operation being performed, localized expansion may result in overcuts or undercuts and drilling a tapered hole.

Machining procedures then, especially working speeds, must take conductivity and expansion effects into account.

Surface speeds from 60–150 m/min (200–500 fpm) are most satisfactory for fine-finish turning operations; at these speeds, flood coolants are not needed. Higher speeds can be used with very low feeds or for rougher cuts, but coolants become a necessity for removal of excess generated heat. A good coolant consists of water plus water-soluble oil in a ratio of 10:1 to 20:1.

Feeds for the 60–150 m/min (200–500 fpm) speed range should run between 0.05–0.25 mm (0.002–0.010 in) per revolution. If a finishing cut is the object of a high-speed operation (e.g., an automatic screw-machine running at 240 m/min [800 fpm]), then feed must be dropped to a correspondingly lower value. Recommended depth of cut varies from 0.005–6.3 mm (0.0002–0.25 in).

In drilling operations, the forward travel of the tool should be held to 0.13–0.23 mm (0.005–0.009 in) per revolution. It may prove advantageous to drill with an in-out motion to allow dissipation of heat into the coolant.

**Properly Shape and Use Tools**

Along with working speeds, choice of tools is quite important to control heat buildup. While standard tools can be used, best results come from tools specifically shaped for use with Teflon™ PTFE fluoropolymer resins. The table below presents shape information important to proper single-point tool design:

<table>
<thead>
<tr>
<th>Top rake</th>
<th>0–15° positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side rake and side angle</td>
<td>0–15°</td>
</tr>
<tr>
<td>Front or end rake</td>
<td>0.5–10°</td>
</tr>
</tbody>
</table>

Boring tools normally require the higher angles listed.

The quality of a tool’s cutting edge not only influences the amount of heat generated, but also controls tolerances in a different way. A tool that is not sharp may tend to pull the stock out of line during machining, thereby, resulting in excessive resin removal. On the other hand, an improperly edged tool tends to compress the resin, resulting in shallow cuts.

An extremely sharp edge is, therefore, highly desirable, especially for machining work on filled compositions. “Stellite” and carbide-tipped tools will help to minimize required re-sharpening frequency.

To partially compensate for tool wear, it is helpful to grind tools with a slight nose radius. All drills, either twist or half-round, should have deep, highly polished flutes.

Adequate material support is also important, especially when machining long, thin rods of Teflon™ PTFE fluoropolymer resins. If support is not provided, stock flexibility may lead to poor results.

Another characteristic of Teflon™ PTFE fluoropolymer resins will be noted immediately after beginning any turning operation. Rather than chips and ribbons of removed stock, as encountered during the machining of most materials, a Teflon™ PTFE fluoropolymer resin turns off as a long, continuous curl. If this curl is not mechanically guided away from the work, it may wrap around it, hampering the flow of coolant, or worse, forcing the work away from the tool. On an automatic screw machine, a momentary withdrawal of the tool from the stock will suffice.
**Rules for Dimensioning and Finishing**

Normally, Teflon™ PTFE fluoropolymer resins are machined to tolerances of about 0.13 mm (±0.005 in.). While closer tolerances are occasionally required, they usually are not necessary. The natural resiliency of these resins allows machined parts to conform naturally to working dimensions. For example, a part with an interference can be press-fitted at much lower cost than that required for final machining to exact dimensions, and the press-fitted part will perform equally well.

**Closer Tolerances**

When it is necessary to produce shapes with extremely close tolerances, it is usually essential to follow a stress-relieving procedure. By heating a fluoropolymer resin stock to slightly above its expected service temperature (but below 327 °C [621 °F]), initial stresses are relieved.

Holding this temperature for 1 hr per 2.5 cm (1 in) of thickness, followed by slow cooling, completes the initial annealing step. (Stress-relieved stock can also be purchased from processors.) A rough cut will then bring the stock to within 0.38–0.76 mm (0.015–0.030 in) of final dimensions. Re-annealing prior to a final finishing cut will remove stresses induced by the tool.

A transition occurs in Teflon™ PTFE fluoropolymer resin, resulting in a 1–1.5% increase in volume as temperature is increased through the neighborhood of 19 °C (66 °F). This must be considered when measuring a part for a critical application.

**Measuring Tolerances**

Personnel should exercise caution when measuring tolerances on parts machined from Teflon™ PTFE fluoropolymer resins; in general, results will be better if the measuring instruments do not exert excessive pressure on the piece.

For example, a micrometer used by inexperienced personnel could easily read 0.13–0.25 mm (0.005–0.010 in) under the true dimension because of the compressibility of the Teflon™ PTFE fluoropolymer resin being used. Optical comparators are often useful in eliminating this type of error.

It is best to check dimensions at the expected service temperature; but, temperature compensations will suffice if this is not practical. Parts machined to final size and measured at room temperature or below will not meet specifications at higher temperatures. The reverse is also true.

**Surface Finishes**

Surface finishes better than 0.4 µm (16 µin) are possible on parts made with Teflon™ PTFE fluoropolymer resins, but rarely are needed because of the resin's compressibility and low coefficient of friction. Precision-honed and lapped cutting tools will produce a 0.4-µm (16-µin) surface when required; standard equipment yields a finish of about 0.8 µm (32 µin).

Lapping compounds may be used, but these as well as grinding compounds may become embedded in the fluoropolymer and may prove to be very difficult to remove. Contaminants from machinery not used exclusively for Teflon™ PTFE fluoropolymer resins can also embed in the resin surface.

**Safe Handling**

**WARNING! VAPORS CAN BE LIBERATED THAT MAY BE HAZARDOUS IF INHALED.**


Open and use containers only in well-ventilated areas using local exhaust ventilation (LEV). Vapors and fumes liberated during hot processing of Teflon™ PTFE fluoropolymer resin should be exhausted completely from the work area. Contamination of tobacco with these polymers must be avoided. Vapors and fumes liberated during hot processing that are not properly exhausted, or from smoking tobacco or cigarettes contaminated with Teflon™ PTFE fluoropolymer resin, may cause flu-like symptoms, such as chills, fever, and sore throat. This may not occur until several hours after exposure and will typically pass within about 24 hr. Mixtures with some finely divided metals, such as magnesium or aluminum, can be flammable or explosive under some conditions.
Teflon® PTFE Fluoropolymer Resins

**Typical Applications**

- **Flexible Pipe Joint**
- **Filled Seals**
- **Heat Exchanger Tube Sheet**
- **Chemical Transfer Hose**
Teflon® PTFE Fluoropolymer Resins

Tubing

Electrical Insulators

Valve Body
References


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Replaces: H-37051-4
C-11547 (3/18)