ADHESIVE PROPERTIES

Because of its inherent anti-adhesive properties, TEFLON cannot be glued. Etching the PTFE by either chemical methods or by corona discharge modifies the surface composition so that cementing with adhesives becomes feasible.

Filled PTFE shows much better bond strengths than unfilled PTFE (table 12). With most compounds etching is still recommended. With 1192-N, the bond strength is so high that, upon peeling, the TEFLON itself is torn apart while the adhesive bond remains intact. 1192-N can therefore be glued without surface pretreatment.

FOOD CONTACT

Finished articles which have been properly fabricated from fluorocarbon resins by high temperature procedures (sintering of PTFE) are considered suitable for food contact and can be in full compliance with FDA regulations for food contact. It is the responsibility of the company that places articles on the market to make sure that these articles comply with the regulations (FDA 21 CFR 177.1550). Unprocessed resins are not in compliance; only finished articles made from them can be.

Of the filled compounds, Du Pont considers the ones with glass, carbon and bronze suitable for food contact. For questions on other compounds, contact your local Du Pont representative.

ELECTRICAL PROPERTIES

TEFLON PTFE is known for its outstanding electrical properties – high dielectric strength, low dielectric constant and very high electrical resistance. How the addition of filler changes these properties is shown in tables 13 and 14.

With the exception of carbon-filled compounds, the compounds shown in Table 14 are still excellent electrical insulators. Compounds filled with MoS_2 are better insulators than those filled with graphite or carbon.

Due to porosity of TEFLON compounds, their insulating properties deteriorate with increasing humidity. Absorption of liquids can further impair their electrical properties.

For applications where good mechanical properties and high dielectric strength are required, compounds filled with ultra-pure aluminium oxide or calcium fluoride are recommended.

TRIBOLOGY: WEAR, FRICTION AND ABRASION

When looking into wear and friction properties of pure TEFLON PTFE and filled TEFLON compounds, it is important to keep in mind that wear and friction are two distinct and independent variables. Unfilled PTFE has a very low coefficient of friction but it wears fast. By adding fillers, the friction coefficient changes only marginally, while the wear rate is reduced rapidly. Furthermore, one should keep in mind that wear experiments can only be done on **two** mutually interactive materials. While the wear of the surface of the TEFLON compound may be small, the mating surface may be worn very fast – a phenomenon called abrasion. For bearing applications of TEFLON compounds, one has to look into all three characteristics: wear, friction and abrasion. The number of variables that affect wear, friction and abrasion is large (Table 15). This explains why one can find in the literature so many confusing and even conflicting data. The conditions under which wear, friction and abrasion have been measured should be studied carefully.

For critical applications, testing is strongly recommended under conditions which approach those of the actual application as closely as possible.

Some of the factors that play a role in the tribological properties of TEFLON compounds are reviewed in the following paragraphs.

TABLE 15.

FACTORS THAT AFFECT TRIBOLOGICAL PROPERTIES

Load
Velocity
Movement – rotating/reciprocating
Degree of coverage
Ambient temperature
Filler – percentage
    nature
    morphology
Preparation method of the finished part
Running-in conditions
Mating surface:
– material
– surface roughness
Lubrification
Environment
Entrapped wear debris

1. Load and velocity

The influence of load and velocity on the wear and friction of TEFLON and TEFLON compounds has been studied by several authors, and a large number of models have been developed over the years.

For the **coefficient of friction,** the generally accepted formula is:

$f = CP^{-0,1}$
f = coefficient of friction
C = constant
P = pressure, N/mm^2

Some authors report a weak dependence of C on velocity, with C decreasing if the velocity is less than 1 cm/sec. f is relatively constant over a broad range of conditions, with lowest values of 0,04 in low velocity/high pressure conditions and maximum values of about 0,5 with combinations of high velocity and low pressure.

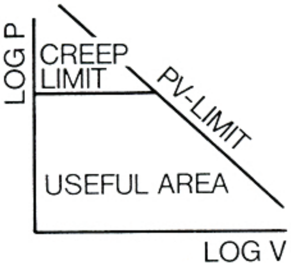
For **wear**, Lewis's formula is frequently used:

$W = KPV$
W = volume wear rate, cm^3/s.
K = wear factor, cm^2/N
P = load, N
V = velocity, m/sec.

This formula is valid for wear against steel and between certain boundaries of PV. Above the upper boundary, commonly known as the "limiting PV-value" or "PV-limit", the wear rate increases exponentially. This is because the heat generated by rubbing builds up in the material, and the temperature starts to exceed the transition temperature of TEFLON (327 °C). It has become common practice to express the wear properties of TEFLON compounds by this PV-limit and by the wear factor K.

One has to bear in mind that not every combination of PV below the PV-limit can be used in practice, as at very high pressures the material starts to creep (see fig 4).

FIG. 4 USEFUL PV-AREA



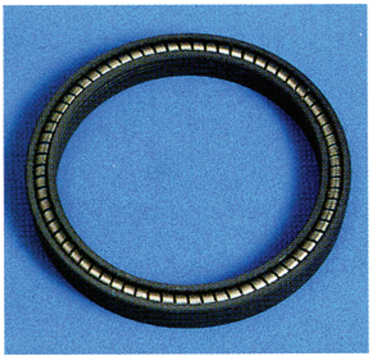
2. Ambient temperature

The useful temperature range for continuous use of TEFLON compounds is extremely broad. TEFLON is one of the few polymeric materials that can be used in a cryogenic environment; this is why it is often used in spacecraft and satellites that operate in outer space. At the upper end of their temperature range, TEFLON compounds can withstand 260 °C continuously, or 360 °C for short periods. The coefficient of friction of TEFLON compounds is almost constant above 0 °C, but is slightly higher in the cryogenic range. The same is true for wear rate. However, the heat developed during the rubbing process builds up in the material, thereby effectively raising the surface temperature. This implies that at higher ambient temperatures, the PV-limit is lowered.

3. Filler

The nature of the filler, the percentage of filler present and its morphology (particle size, shape and structure) all influence the tribological properties of TEFLON compounds.

The **coefficient of friction** (f) is the least affected by fillers. The lowest values of f are attained with compounds containing graphite or MoS_2 alone or in a combination with glass fibre. For all other fillers, f is about the same. The percentage of filler also affects the coefficient of friction: f generally goes through a minimum at 20 per cent by volume of filler (for a conversion from percentage by volume to percentage by weight, see p. 4).



The **wear behaviour** of TEFLON compounds is more complex. As with the coefficient of friction, the wear rate goes through a minimum - at about 20 per cent by volume - as the percentage of filler is increased. However, the nature of the filler plays a much more important role. There is a large amount of data in the literature on the influence of adding specific fillers on wear rate, but as there are no standard test conditions for wear, it is dangerous to draw conclusions from this data. Under average wear conditions against mild steel, the sequence shown in the following diagram provides useful guidance:

low wear **against mild steel** **high wear**

– glass/MoS_2 – carbon/graphite – glass fibre
– graphite
bronze
– MoS_2
– glass/graphite – carbon fibre
– unfilled

Under severe wear conditions (high load, high velocity) the order changes. One reason is that the amount of heat developed at the surface can be so large that the PTFE matrix starts to lose its integrity. Compounds with high thermal conductivity, such as those filled with graphite or bronze, perform best under these conditions.

The morphology of the filler also plays a role. Fibrous fillers show less wear than particulate ones. Compounds with glass beads wear particularly fast; irregular-shaped bronze is better than spherical bronze. Very fine filler particles lead to higher wear rates than particles which are similar in size to those of the base resin itself. Finally, compounds with fillers with a high length/diameter ratio (aspect ratio) will show anisotropy, i.e. the tribological properties in the moulding-direction will be different from those in the cross-direction.

In bearing applications, TEFLON compounds are not only subject to wear themselves – they also abrade the mating surface.

With the normal range of fillers, and against mild or hardened steel, this should not be a problem. However, if the mating surface is aluminium, fillers need to be selected more carefully. The same is true in cryogenic applications, as the steel alloys preferred for low temperatures are sensitive to abrasion.

The following diagram is offered for guidance:

low abrasion **high abrasion**

carbon/graphite
polymeric fillers - graphite - bronze - - glass fibre - minerals - ceramics
carbon fibre

On the other hand, if the surface roughness of the mating surface is high, a more abrasive compound gives better wear results for any given combination of compound and mating surface.

4. Preparation method of the finished part

We have already discussed how the method of preparation of the finished part can affect its physical properties. The same is true for its tribological properties. It has been reported that high crystallinity of TEFLON results in increased wear.

5. Mating surface

Material and surface roughness of the mating surface are important variables in predicting wear. The tribological properties of TEFLON compounds against mild steel have already been discussed.

Against **hardened** steel, the general wear pattern remains the same, although the wear rate is usually lower. Soft metals should be used in combination with less abrasive fillers. Bronze or copper alloys should not be used in contact with bronze-filled compounds.

Both friction and wear increase as surface roughness increases. Where the mating surface is rough, compounds with abrasive components like glass or ceramic perform better, as they tend to polish the opposing face. This also explains why initial wear on a clean surface is usually different from wear after an initial running-in period. The wear rates indicated in this chapter refer to "steady state" conditions after such a running-in period.

6. Lubrication

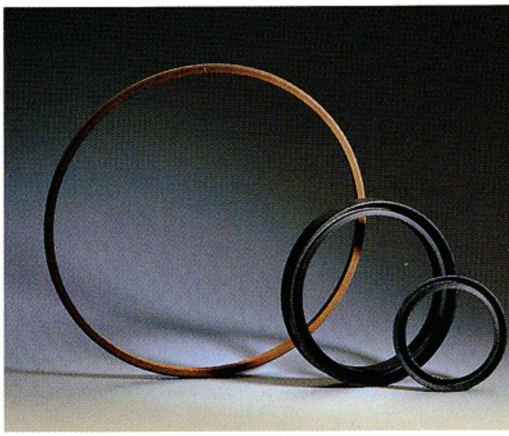
TEFLON compounds do not need to be lubricated; that is one of their main attractions in use for bearings. Yet there can be circumstances where a lubricant or a process liquid is in contact with the surface. Almost without exception, the coefficient of friction of compounds is decreased by the presence of a lubricant, whether it is water, a lubricating oil or a solvent. But – perhaps surprisingly – the wear rate goes up in the presence of a lubricant. The reason, however, is simple. Under non-lubricated, dry conditions a very thin layer of PTFE is transferred to the mating surface and acts as an effective dry lubricant. But the presence of a liquid prevents or hinders this PTFE transfer. The degree to which it nevertheless happens depends on the nature of the liquid.

Water greatly increases the wear rate of TEFLON compounds, especially that of glass-filled types. Carbon/graphite compounds show the best performance. The following diagram is offered for guidance:

low wear **in water** **high wear**

carbon/graphite
- glass/MoS_2 - bronze - graphite - glass - unfilled
carbon fibre

When surfactants are added to the water, and the surface tension is decreased to less than about 27 dyne/cm, the wear rate decreases sharply.



7. Environment

The environment also affects the wear properties of TEFLON compounds. At very low moisture levels in air (40 ppm or lower) wear rates increase. This is particularly the case for compounds containing graphite, as this material tends to disintegrate when no moisture is present. The nature of the ambient gas also has an influence. Wear rate in nitrogen and helium is reported to be lower than in air.

8. Entrapped wear debris

During the process of wear, debris is formed, consisting of particles of filler, of TEFLON and of the mating surface. Thus, wear rates can be lowered if the geometry of a bearing allows debris to be expelled from the bearing. This can be done e.g. by machining radial grooves in a bearing surface. This is particularly effective with bronze-filled compounds.

LITERATURE

There is abundant literature on the tribology of TEFLON and TEFLON compounds. A selection is given below.

K. Friedrich (Ed.), Friction and Wear of Polymer Composites, Elsevier, Amsterdam, 1986

H. Uetz and J. Wiedemeyer, Tribologie der Polymere, Hanser Verlag, München, 1985

R.B. Lewis, Predicting Bearing Performance of filled TEFLON TFE resins, ASME Paper no. 66-WA/RP-1.

R.B. Lewis, W.D. Lewis and J.T. O'Rourke, Performance of TEFLON Fluorocarbon Resins as Bearing Materials, ASME Paper no. 61-WA-334.

Du Pont Technical Information, A Tribological Characterization of TEFLON PTFE compounds.

CHEMICAL RESISTANCE

The chemical resistance of TEFLON PTFE is excellent. It is stable in most aggressive and corrosive media, exceptions being liquid or dissolved alkali metals, fluorine and other extremely potent oxidisers.

The resistance of TEFLON compounds to a number of chemicals is given in Table 16. In general, carbon and glass-filled compounds give better performance in chemical service.