

DU PONT DE NEMOURS (E.I.) AND COMPANY
WILMINGTON, DEL. POLYCHEMICALS DEPT.

TEFLON, TETRAFLUOROETHYLENE RESINS:
PROPERTIES, USES.

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TEFLON[®]

tetrafluoroethylene resins

dielectric
properties

chemical
inertness

heat-
resistance

toughness
and
flexibility

low
coefficient
of friction

water
absorption
less than
0.01%

weather-
resistance

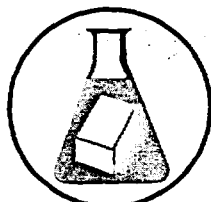
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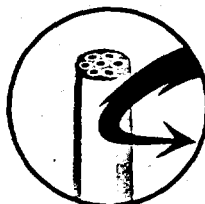
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Products made from Du Pont **TEFLON[®]** *tetrafluoroeth*

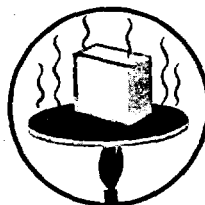
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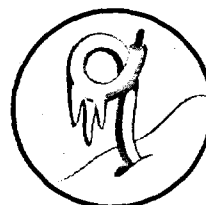
chemical inertness



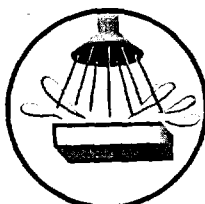
dielectric properties



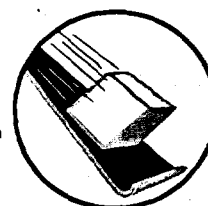
heat resistance



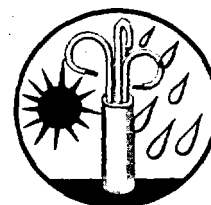
toughness and flexibility



water absorption less than 0.01%



low coefficient of friction



weather resistance

ns offer this unexcelled combination of properties.

DIELECTRIC PROPERTIES—Low power factor, low dielectric constant; high volume and surface resistivity, good dielectric strength . . . all constant over a wide range of frequencies and temperatures.

CHEMICAL INERTNESS—Inert to nearly all chemicals and solvents. Exceptions to this include attack by the alkali metals under certain conditions. At elevated temperatures and pressures, halogens and certain halogenated chemicals and solvents may affect it.

HEAT RESISTANCE—Capable of continuous service at 500°F.

TOUGHNESS AND FLEXIBILITY—Remain tough even at extremely low temperatures.

LOW COEFFICIENT OF FRICTION—Unique slippery surface resists adhesion to most materials.

MOISTURE ABSORPTION—Less than 0.01% by ASTM test.

WEATHER-RESISTANCE—Absolutely no recorded change in properties after 10 years of outdoor exposure.

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TEFLON[®] *tetrafluoroethylene resins*

PROPERTIES

USES

"Teflon" is a registered trademark of the Du Pont Company. "Teflon" tetrafluoroethylene resins have a combination of electrical, chemical, and thermal properties unmatched by any other single material. These properties have established "Teflon" tetrafluoroethylene resins as outstanding materials for use in electrical insulation at high frequencies and high temperatures; as a gasket and packing material in the chemical processing industries; and in many other applications.

History

"Teflon" tetrafluoroethylene resins are members of the fluorocarbon family, and an outgrowth of the same Du Pont research that led to the development of the "Freon"¹ series of refrigerants. The commercial production of "Freon" refrigerants, compounds consisting of fluorine, carbon, and (usually) chlorine, began in 1931. Further research on this family of products led to the laboratory discovery of the first tetrafluoroethylene resin in 1938. Semi-plant production of "Teflon" tetrafluoroethylene resins began in 1941; and the first commercial plant, at Parkersburg, West Virginia, started operation in 1950. Continuing research has resulted in the development of a variety of tetrafluoroethylene resins, and in the continual improvement of fabricating techniques.

¹Organic Chemicals Department, Du Pont Company.

General Characteristics

Fabricated shapes of "Teflon" tetrafluoroethylene resins are tough, flexible in thin sections, and fairly rigid in massive pieces. They maintain their useful mechanical properties at temperatures in the range from -450°F. up to 500°F. or more. Their surfaces manifest an extremely low coefficient of friction, and almost nothing sticks to them. However, by special treatments (discussed on page 27) these surfaces can be made to accept conventional industrial adhesives. "Teflon" tetrafluoroethylene resins are almost completely inert to chemical attack, being affected only by such substances as liquid alkali metals and fluorine. The low-loss electrical characteristics of the resins remain essentially constant, regardless of frequency, over a wide range of temperature.

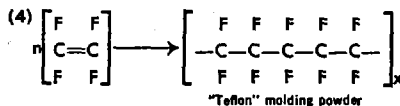
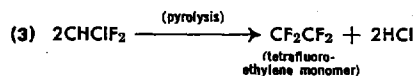
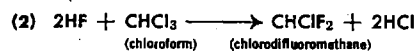
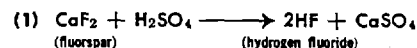
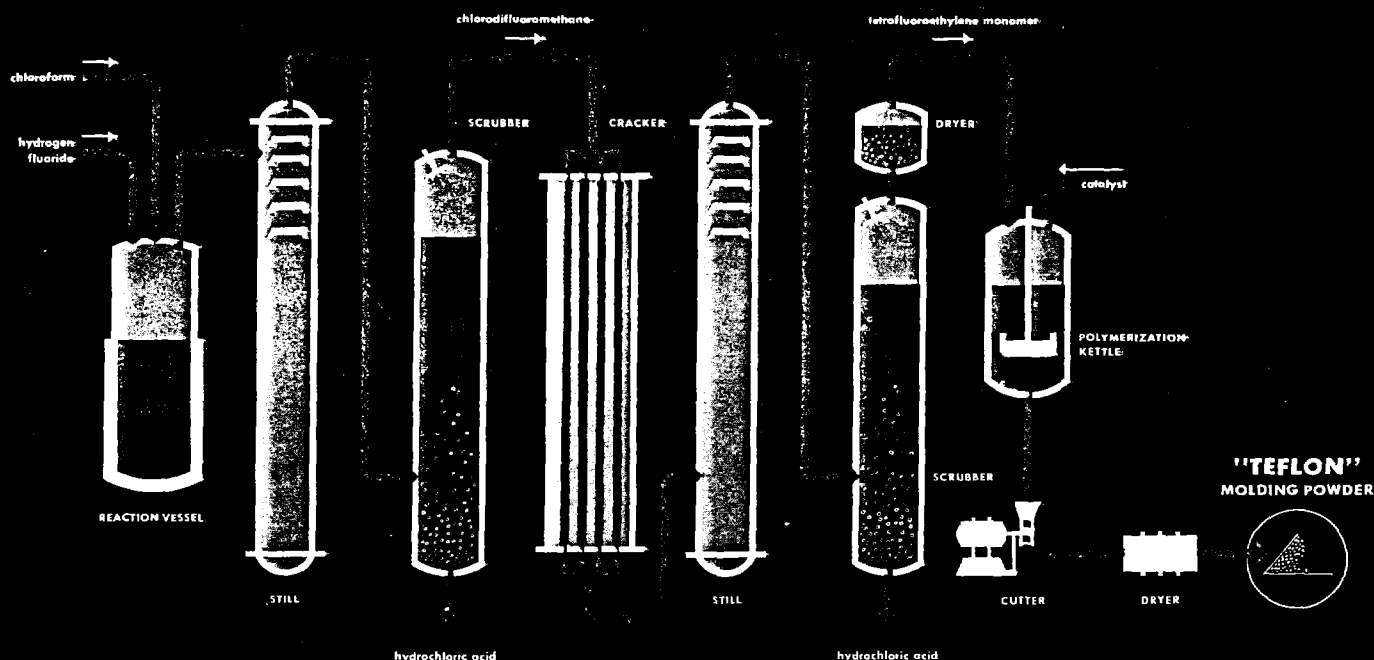


"Teflon" tetrafluoroethylene resins are unique materials, differing in important respects from conventional thermoplastic and thermosetting resins. In their usual state at ordinary temperatures, they tend to be opaque, crystalline, and malleable. On being heated above 620°F., they become transparent, amorphous, and relatively intractable, fracturing if severely deformed. They return to the opaque, crystalline malleable state on being cooled below 620°F.

In the particular forms supplied to processors, "Teflon" tetrafluoroethylene resins can be aggregated into dense coherent shapes at tem-

peratures below 620°F. by means of various "cold-forming" techniques. The cold-formed products then can be strengthened, if desired, by a process called "sintering," which involves heating the pre-formed resin at temperatures above 620°F., and cooling below 620°F. The sintered products may then be further shaped by various post-forming techniques, most readily at temperatures approaching but below the 620°F. transition temperature. Cold-forming, sintering, and post-forming are the techniques most commonly employed in the processing of "Teflon" tetrafluoroethylene resins into useful articles.

FIGURE 1—Some of the more important steps in the manufacture of "Teflon" molding powder



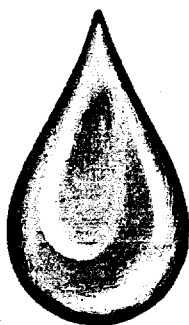
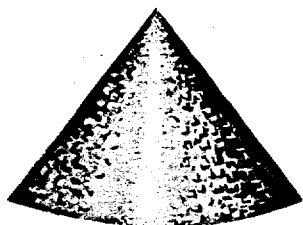
Manufacture

The manufacture of a "Teflon" molding powder is illustrated in the flow sheet (Figure 1). Fluorspar (calcium fluoride) and sulfuric acid are reacted to give hydrogen fluoride, which is reacted, in turn, with chloroform to give chlorodifluoromethane. This is converted by pyrolysis to gaseous tetrafluoroethylene monomer. The monomer is subsequently polymerized under high pressure and temperature.

The polymer consists of long straight-chain molecules packed closely together. This struc-

ture and the strong chemical bond between carbon and fluorine in the molecule impart exceptional resistance to heat and chemicals.

"Teflon" tetrafluoroethylene resins manufactured by the Du Pont Company are available as powder and as aqueous dispersion. The "Teflon" powders are used in molding and extrusion processes. The "Teflon" aqueous dispersions are used in coating, film-casting, impregnating, and the production of compositions containing additives.



Compositions

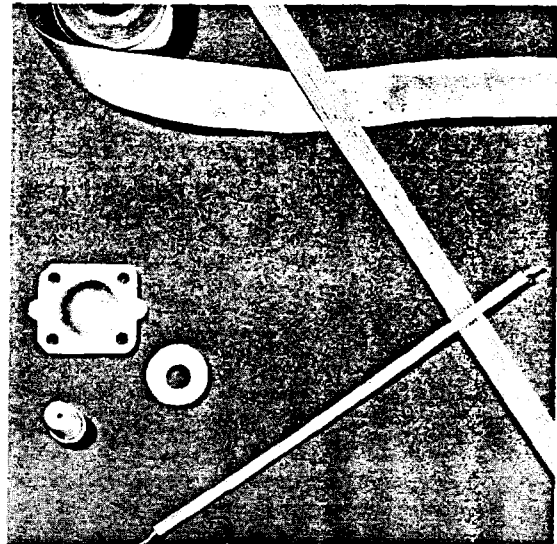
The Polychemicals Department of the Du Pont Company supplies "Teflon" tetrafluoroethylene resins as a series of powders and aqueous dispersions. The basic characteristics of each are described below.

Granular Molding Powders. These are supplied in different granulations, tailored to specific uses. The general-purpose molding powder is a white granular powder with a particle size of about 30 mesh. Its bulk density is about 500 grams per liter. It is processed by molding, and by special ram and screw extrusion techniques.

Other Powders. Special powders are supplied for the extrusion of articles of thin cross-section. When compounded with an extrusion aid such as naphtha, they can be readily extruded as tape, tubing, wire insulation, and shapes.

Aqueous Dispersions. These are hydrophobic colloids with negatively charged particles. They contain 30-60% solids by weight and are stabilized with non-ionic wetting agents. The dispersions are normally supplied with a pH of 10 ± 0.5 .

"Teflon" tetrafluoroethylene resins are converted into tape, sheets, rods, tubes, coated fabrics, coated wire, wire enamels, molded parts, etc., by a number of manufacturers.



Uses

Electrical Applications—Because of their unique combination of electrical, thermal, and mechanical properties, “Teflon” tetrafluoroethylene resins are used extensively by the electrical industry, particularly in insulation for use at high frequencies and high temperatures.

Tetrafluoroethylene resins offer many advantages for such uses, permitting improved design in many cases and providing unexcelled performance. The polymers can be made into thin, flexible insulation in many instances where such an insulation would previously have been impossible. In some types of electrical equipment, it permits miniaturization and compactness of design. Because of its resiliency and toughness, the use of components molded of “Teflon” tetrafluoroethylene resins frequently simplifies installation. Tape made from the resins is easy to handle, conforms well to corners and odd shapes, and is readily adaptable to automatic wrapping operations.

Wire and Cable. Tetrafluoroethylene resins are used for the insulation of many types of wires and cables. Specific fields of application include motors, generators, and transformers of all types; and aircraft, automotive, communications, electronics, locomotive, and marine equipment.

Wire insulated with enamels made from the polymer is used in fractional motors, electronic transformers, thermocouples, and control equipment (such as aircraft controls). The primary advantages contributed by “Teflon” tetrafluoroethylene resins in wire of this type are high service temperature and low power loss they make possible.

Wire with insulation of medium thicknesses is used in electronic applications (as hook-up wire), distribution and power transformers, and aircraft, integral, and traction motors; and under corrosive conditions (as in chemical plants).

Thick-walled insulations made of “Teflon” tetrafluoroethylene resins are used in coaxial cables for radar and television, and on wire designed for use under conditions of high voltages and high temperatures. The excellent dielectric characteristics of these products over the full frequency range make them outstanding for these applications.

Motors and Generators. Articles made of “Teflon” tetrafluoroethylene resins give outstanding performance in many sizes and types of electric motors and generators, especially when service temperatures are too high for other dielectrics, when ruggedness and dependability are paramount, or when motors

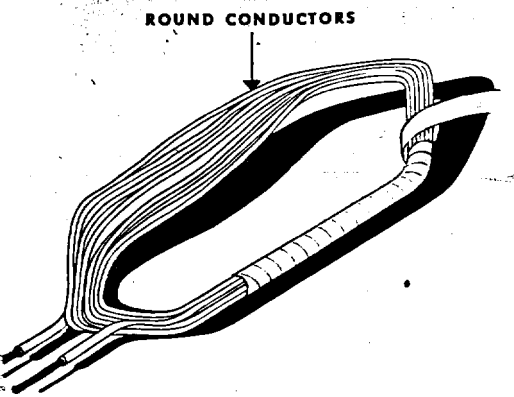


FIGURE 2—Taping of mush-wound coils

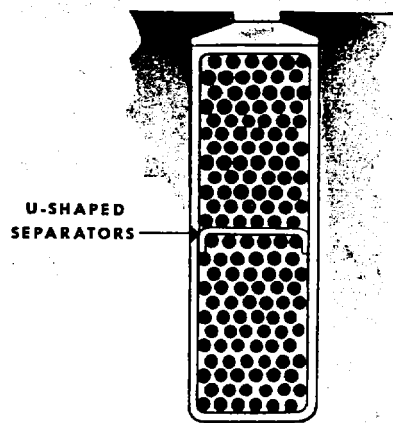


FIGURE 3—Coil separators

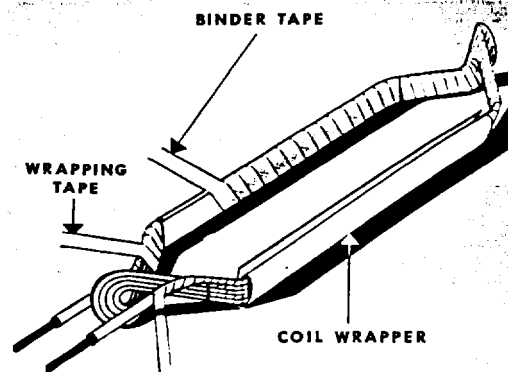


FIGURE 4—Coil wrappers

must operate in corrosive atmospheres.

Tape made from the resins is particularly suitable for use in motors and generators. Uses include conductor insulation for armature or field, coil wrappers, slot liners, taping of coils, lead insulation, and coil separators within slots. These uses are illustrated in Figures 2-6.

In addition to these uses in tape-wrapped constructions, fine wire coated with enamels made from one of the polymers is used in synchronous and fractional motors, and wire insulated by extrusion or calendering (as well as by tape-wrapping) is used in integral and traction motors.

A motor will tend to run more coolly with an insulation of a "Teflon" tetrafluoroethylene resin than with other materials. Although the thermal conductivity of these resins is lower than that of some conventional insulating materials, the heat transfer of an insulation made of "Teflon" tetrafluoroethylene resins is better because it is a compact, solid structure.

Transformers and Coils. With the development of new fabricating techniques for the resins, it is now possible to design transformers capable of operating at hot-spot temperatures as high as 550°F. Tetrafluoroethylene resins also permit considerable simplification of design and reduction in size of equipment, as compared to the use of sealed containers containing liquid or gas dielectrics.

The polymers are used in transformers as conductor, layer, and ground insulation, and for coil separators. This insulation is applied

by a variety of methods, depending on the requirements of the particular application. For electronic transformers, the wire is coated with enamel made from a tetrafluoroethylene resin. For distribution transformers (Figure 7), the wire is insulated by extrusion or calendering, or taped constructions can be used. Such constructions as that shown in Figure 7 can be fused after assembly, excluding air and providing a compact coil unit.

For power transformers, tetrafluoroethylene resin is used as conductor and layer insulation in the forms of tape and laminates made from glass cloth coated with the aqueous dispersion. Laminates provide high resistance to cut-through and abrasion.

Capacitors. Tetrafluoroethylene resins are giving outstanding service in electronic and line capacitors where ambient temperatures are high and minimum power loss is essential. They are used as the dielectric in wrapped capacitors.

Two layers of cast tape are used between conductor plates for the electronic capacitors, while two layers of shaved or extruded tape are used in the line types. Much higher dielectric strength can be achieved by use of two layers than by a thicker single layer.

Power Distribution Equipment. Because articles made of it have resistance to heat, weather, and moisture, and a low loss factor, "Teflon" tetrafluoroethylene resins are particularly suitable for use in power distribution equipment. These uses include insulation for

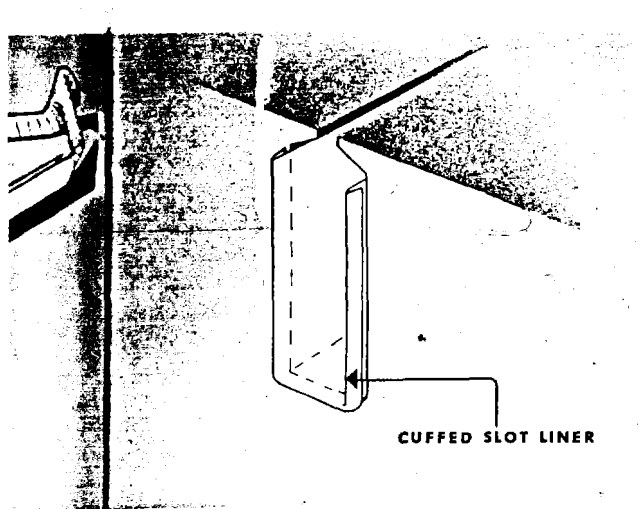


FIGURE 5—Slot liners

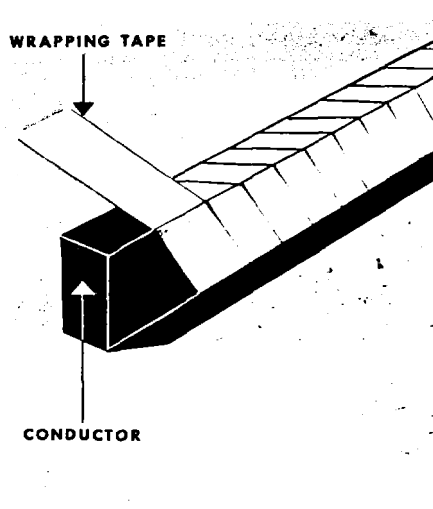


FIGURE 6—Conductor insulation for armature or field

wire and cable, and insulation for motors, generators, and transformers. The use of laminates of glass fabric coated with "Teflon" aqueous dispersion is also important in components for power distribution equipment.

Electronics Equipment. "Teflon" tetrafluoroethylene resins are used in electronics equipment as molded components, tape, and extruded insulation. The excellent dielectric properties of these resins, even at ultra-high frequencies, and their moisture-resistance are particularly important in the electronics field. Heat-resistance is frequently essential, too, especially with the present trend to miniaturization of electronics equipment, which results in increased operating temperatures.

Components molded of "Teflon" tetrafluoroethylene resins include tube sockets, inserts for coaxial connectors, coaxial spacers, bases for sub-assemblies, terminals, and small stand-off insulators. A variety of types and sizes of high-temperature hook-up wires for electronic appliances are insulated with "Teflon" tetrafluoroethylene resins for their combination of properties not otherwise obtainable in a thin, flexible jacket. Such insulation is either extruded or tape-wrapped.

Other uses of tape made from a "Teflon" tetrafluoroethylene resin include layer insulation and coil separators. Thin film cast from the dispersion is used for electronic capacitors, and for wrapping small components. Laminates of glass fabric coated with "Teflon" dispersion are used for terminal boards, bases

for printed circuits, and sub-assembly mounting boards.

Chemical Equipment Applications — The first commercial use of a "Teflon" tetrafluoroethylene resin was a gasket exposed to a boiling mixture of sulfuric and nitric acids. It proved so successful in this case that it has since been employed in hundreds of applications in the most difficult services encountered in the chemical industry. In many instances, "Teflon" tetrafluoroethylene resins have been found to be the only materials that would give satisfactory performance. In others, they have reduced maintenance requirements, lowered replacement costs, reduced wear on pistons and shafts, increased productive capacity

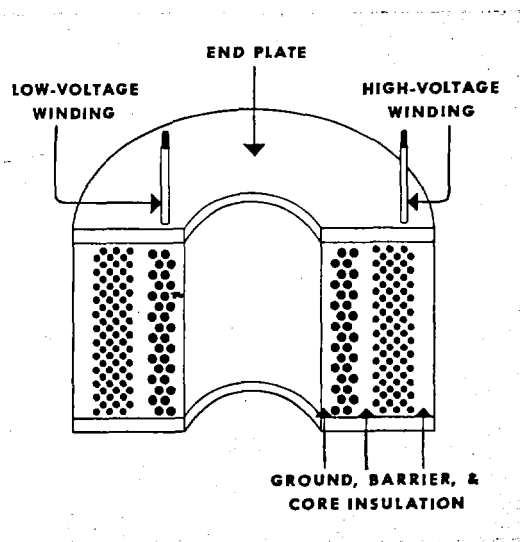


FIGURE 7—Distribution transformer coil

through less down-time, and permitted simplification of design. The use of these resins also frequently improves the quality of the products being processed because they do not contaminate materials being processed.

Gaskets. All types of gaskets are made of "Teflon" tetrafluoroethylene resins. For some uses, solid gaskets give satisfactory service. Many other applications are better served by one of a variety of jacketed and spiral-wound gaskets.

Envelope gaskets, in which a filler is enclosed in a shield made of a "Teflon" resin (Figure 8), are used where bolting pressures are limited, as in the case with comparatively fragile pipe made from ceramics, glass, or carbon, and glass-lined equipment.

Spirally-wound gaskets and gaskets made from asbestos and glass cloth impregnated with "Teflon" dispersion are used in high-pressure installations. Thus the unique properties of "Teflon" tetrafluoroethylene resins are applied to such gasket applications as pipe joints, valve bodies, reaction kettles, steam couplings, pump bodies, packaging closures, and containers for compressed gases.

Gaskets made of "Teflon" tetrafluoroethylene resins have been used successfully in contact with bromine, chlorine, sulfur dioxide, concentrated sulfuric acid, aqua regia, thionyl chloride, organic solvents of all types, and

many, many other corrosive materials.

Packings. Packings made from these resins are also supplied in many forms. Solid rings are completely impervious to gases and liquids, and have the advantage of simplicity. They are used singly or in series. Tapered wedge rings molded from a "Teflon" tetrafluoroethylene resin have an advantage over solid rectangular rings in some cases, because they can be seated with lower gland forces.

Braided packings are made of twisted ribbons of one of the polymers usually in combination with asbestos yarn. These packings are suitable for valves and low-speed shafts, and have the advantage of convenience for ready installation in stuffing boxes of various sizes.

"Plastic" packings consisting of a shredded "Teflon" tetrafluoroethylene resin and a binder are easily shaped in the stuffing box. These packings will seal at low gland pressure.

A variety of special shapes such as cup-and-cone rings and "V" rings are also made of tetrafluoroethylene resins. The "V" ring, for example, is designed to provide a seal with a minimum gland pressure between parts having comparatively little relative motion.

Packings made of asbestos braid impregnated with "Teflon" aqueous dispersion provide the chemical-resistance of "Teflon" tetrafluoroethylene resins, while maintaining the strength and resiliency of asbestos fibers.

An example of the use of one of the polymers in high-speed packings is shown in Figure 9. Here, the packing rings are made by shredding a molded piece of "Teflon" tetrafluoroethylene resin and adding a small amount of binder (graphite, mica, or other low-friction modifier) to the shreds to provide the necessary combination of form-stability, resiliency, and abrasion-resistance.

As in the case of gaskets, packings made of the resins have given excellent service in many types of chemical equipment—pumps, valves, agitators, etc.—handling the most corrosive materials. In fact, cases have been reported in which pump packings made of "Teflon" tetrafluoroethylene resins have outlasted conven-

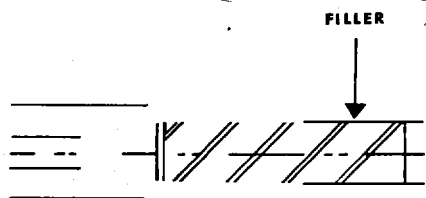
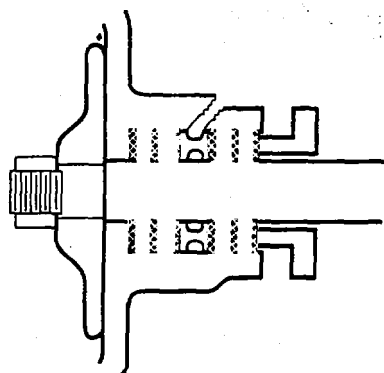


FIGURE 8—Envelope gasket made with a "Teflon" tetrafluoroethylene resin

FIGURE 9—Stuffing box packed with a "Teflon" tetrafluoroethylene resin



tional packings by over 300 times.

Valve Components. Valve components made of tetrafluoroethylene resins give outstanding performance and long service life, providing important savings in labor, material, and production down-time.

Gaskets and packings were among the earliest applications of these resins in valves. When made of "Teflon" tetrafluoroethylene resins these parts normally outlast the valve itself, permit miniaturization of packing glands, and require less torque to open and close the valve.

The use of tetrafluoroethylene resins in valve seats and discs frequently permits inter-

changeability of valve parts and simplification of design, and improves operating characteristics (Figure 10). The resiliency of these polymers is an important factor in their use as a material for valve seats, providing tight, leak-proof seating.

"Teflon" molding powders have also been employed as materials for a liner in plug cock valves (Figure 11). In this application, their use prevents freezing of the plug cock in the body, and eliminates the need for intricate and costly design usually involved in lubricated valves.

Tetrafluoroethylene resins have proved successful in diaphragms for valves of the Saunders type. Some diaphragms for pressure-controlled valves are made either from these resins alone or glass cloth impregnated with "Teflon" aqueous dispersion.

Pump Components. Gaskets and packings made of tetrafluoroethylene resins are used satisfactorily in countless pump applications handling corrosive chemicals under extremely severe conditions.

In mechanical seals (Figure 12), they eliminate the possibility of scoring the shaft, and offer an excellent combination of chemical-resistance and flex life.

"Teflon" tetrafluoroethylene resins are also giving excellent performance in impellers. This rapidly moving component is frequently the

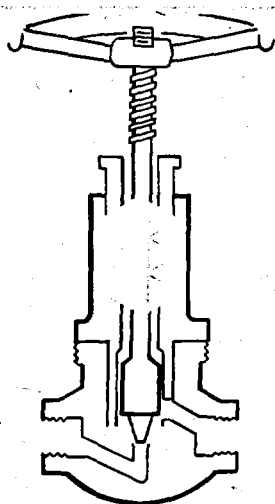


FIGURE 10—Valve with packing and seat of "Teflon" molding powder

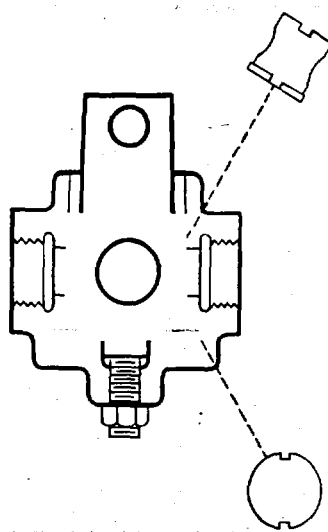


FIGURE 11—Plug valve with liner of a "Teflon" tetrafluoroethylene resin

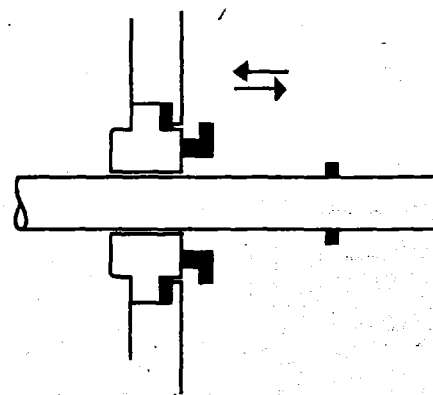


FIGURE 12—Mechanical seal of a "Teflon" tetrafluoroethylene

first element of a pump to fail, because of corrosion and erosion accelerated by the impinging of corrosive fluids. Tetrafluoroethylene resins provide a high degree of resistance to this effect (Figure 13). They are compounded with powdered glass and similar additives for applications of this type, for dimensional stability.

In a similar manner, bearings made of compounded tetrafluoroethylene resins are used in the same pump. The use of these resins for bearings and impellers has greatly extended the range of chemicals that can be handled by the single pump.

Another type of pump impeller is the diaphragm. In this application, "Teflon" tetrafluoroethylene resins are used without being compounded, giving excellent flex life.

Pipe and Tubing. Several types of pipe and tubing are made of tetrafluoroethylene resins. These include:

(1) tubing made from laminate of glass impregnated with "Teflon" aqueous dispersion—both with and without a lining of solid tetrafluoroethylene resin;

(2) thin-wall tubing made from an unsupported "Teflon" molding powder, tetrafluoroethylene resin with an overbraid of wire or cloth, and a compounded "Teflon" molding powder;

(3) pipe (in standard sizes) made of both

solid and compounded tetrafluoroethylene resin;

(4) metal pipe lined with thin-wall tubing made of "Teflon" extrusion compound.

Mechanical Applications—A new, and potentially large, field of application for "Teflon" tetrafluoroethylene resins is that of mechanical parts, primarily bearing surfaces. Of particular importance in this use is its low coefficient of friction. Its form-stability under load is enhanced by use of the proper reinforcing agents, while other properties remain substantially unchanged. In some cases, the chemical inertness of tetrafluoroethylene resins are employed.

The use of "Teflon" tetrafluoroethylene resins as a bearing in pumps, noted under **Chemical Equipment Applications**, is an excellent example of the combination of properties offered by these resins. In this use, chemical inertness plus unusual frictional properties have provided a bearing whose service cannot be matched by those made of other materials.

A bearing made of "Teflon" molding powder compounded with an inorganic material is used on the rolls of a textile twisting machine to make possible the elimination of lubricants and the resulting contamination of goods by oil. This is a half-sleeve bearing which runs on a shaft of cast iron or hardened steel. The shaft turns at about 100-200 r.p.m., and the

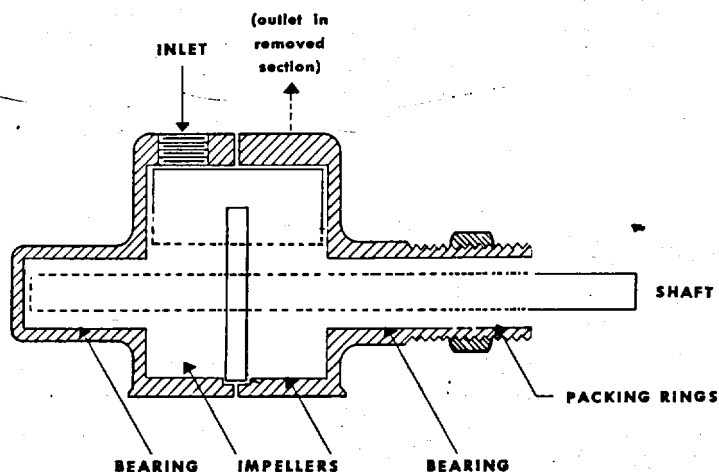


FIGURE 13—Pump with impeller and bearings of a "Teflon" molding powder

bearing is subjected to loads of about 175 lb./sq.in. Tests indicate that the reinforced composition operates satisfactorily without lubricants, and under greater loads and speeds than are normal in textile operations.

Tests are now underway to develop speed and load data on "Teflon" tetrafluoroethylene resins compounded with various reinforcing materials. Where difficult bearing applications are encountered, and particularly where corrosion or high temperatures present a problem, or where normal lubricants cannot be used, these resins compounded with reinforcing agents may provide the answer.

Non-Adhesive Applications—The unique non-adhesive property of articles made of "Teflon" tetrafluoroethylene resins is utilized in a variety of operations in which sticky materials are handled. By covering the critical surfaces of processing equipment with a tetrafluoroethylene resin, the following advantages are realized:

- (1) reduction in time required for cleaning,
- (2) reduction in waste of materials,
- (3) elimination of ingredients added to reduce stickiness,
- (4) improvement of product quality,
- (5) improvement of operating efficiency.

"Teflon" tetrafluoroethylene resins are applied to surfaces for nonadhesive purposes as a solid film or extruded or molded shape, which can be attached to the equipment by mechanical means; as a finish, applied directly to the substrate by use of a primer coat and multiple spraying and fusing operations; or as a glass cloth impregnated with "Teflon" aqueous dispersion.

In general, "Teflon" molding powders are used as tape or sheet when the surface is subjected to hard mechanical usage and may require periodic resurfacing; or where resiliency is needed; or where, because of size or other considerations, it is not feasible to apply a finish.

A finish (made from "Teflon" dispersion) is used where a thin film (e.g., 4 to 8 mils) is desired over a metal substrate.

Glass cloth impregnated with "Teflon" dispersion is used where it is necessary to combine flexibility with strength and dimensional stability in a thin film.

On bread-sheeting rolls, "Teflon" tetrafluoroethylene resins eliminate the need for accurately ground scrapers, otherwise needed to strip the sticky dough from the sheeting rolls. They reduce or eliminate the use of dusting flour to reduce sticking, and make it possible to produce bread of improved quality because a thinner sheet is rolled.

The use of tape made of tetrafluoroethylene resin on heat-sealer plates of wrapping machines eliminates sticking of packaging materials to the sealer plates, and prevents build-up of foreign matter on the plates. Other uses in packaging machinery include guides, dead plates, and hoppers of packaging machines to reduce cleaning and improve operating efficiency.

Tetrafluoroethylene resins are also used for their non-adhesive characteristics in a variety of other applications in food-processing equipment, especially machinery used in the preparation and handling of candy; in the rubber and plastics industries, to prevent sticking to molds and platens; and in industries in which glue is handled extensively.

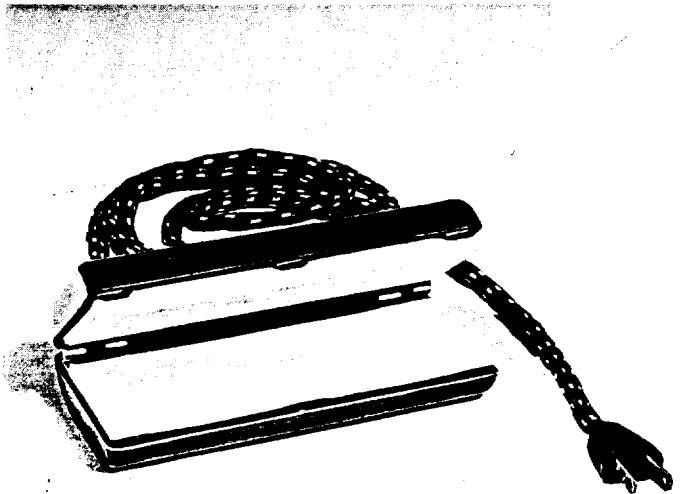


TABLE 1—Properties of molded "Teflon" tetrafluoroethylene resins

PROPERTY	UNITS	A.S.T.M. METHOD	
Tensile strength, 73°F.	lb./sq.in.	D638—52T	1,500—3,000(1)
Elongation, 73°F.	%	D638—52T	100—200
Flexural strength, 73°F.	lb./sq.in.	D790—49T	did not break
Flexural modulus, 73°F.	lb./sq.in.	D747—50	50,000—90,000
Impact strength, Izod, —40°F.	ft.-lb./in.	D256—47T	2.0—3.0
73°F.	ft.-lb./in.	D256—47T	2.5—4.0
Hardness, Durometer		D676—49T	D50—D60
at 1% offset, 73°F.	lb./sq.in.	D695—52T	700—1,200
Coefficient of linear thermal expansion per °F., 73—140°F.		D696—44	5.5×10^{-5}
Thermal conductivity, 0.18 in.	B.T.U./hr./sq.ft./°F./in.	(2)	1.7
Specific heat	B.T.U./lb./°F.		0.25
Deformation under load, 122°F., 1200 lb./sq.in., 24 hrs.	%	D621—51	4—8
122°F., 2000 lb./sq.in., 24 hrs.	%	D621—51	25
Heat-distortion temperature, 66 lb./sq.in.	°F.	D648B—45T	250
Dielectric strength, short-time, 0.080 in.	v/mil	D149—44	400—500(3)
Surface arc-resistance	sec.	D495—48T	(4)
Volume resistivity	ohm-cm.	D257—52T	$> 10^{16}$
Surface resistivity, 100% R.H.	megohms	D257—52T	$> 10^{11}$
Dielectric constant, 60 to 3×10^9 cycles		D150—54T	2.1
Dissipation factor, 60 to 3×10^9 cycles		D150—54T	< 0.0003
Water-absorption	%	D570—42	< 0.01
Flammability	in./min.	D635—44	nonflammable
Specific gravity		D792—50	2.1—2.3
Resistance to weathering			excellent (6)
Static or kinetic coefficient of friction against polished steel		(5)	0.04

Data shown are average values and should not be used for specifications.

(1) Tensile strength in oriented film may be as high as 15,000 lb./sq. in.

(2) Measured by Cenco-Fitch apparatus.

(3) Value is 1000-2000 volts/mil in thicknesses of 12 to 5 mils, 4000 volts/mil for ¼ mil.

(4) Does not track.

(5) Various methods used.

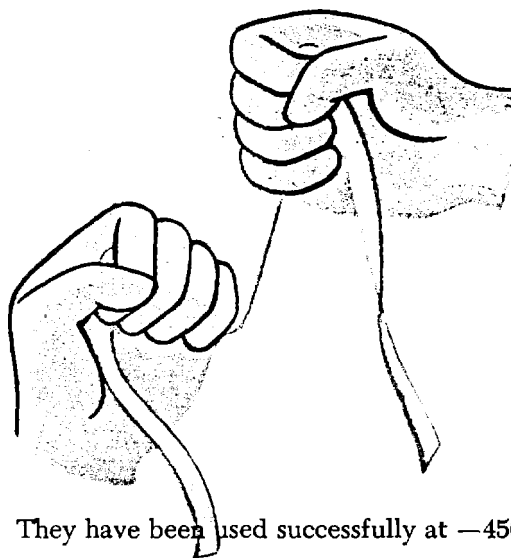
(6) Unaffected by 10 years' exposure in Florida.

Properties

Properties of "Teflon" tetrafluoroethylene resins are given in Table 1. These are representative values, measured on typical molded specimens essentially free of internal stresses. The properties of the various fabricated forms will depend to some extent on method of fabrication.

Thermal Properties—Articles made from tetrafluoroethylene resins have exceptional thermal stability, and are suitable for continuous service at 500°F. The effect of heat on these resins, with respect to weight loss on continued exposure, is shown in Table 2. The stability of "Teflon" tetrafluoroethylene resins is illustrated by the weight loss at 600°F.—only about 0.0002% per hour.

Tetrafluoroethylene resins also maintain good properties at extremely low temperatures.



They have been used successfully at -450°F.

Mechanical Properties — Tetrafluoroethylene resins are relatively flexible, and, as has been noted, retain their flexibility and toughness over a wide range of temperatures. High elongation is evidence of their exceptional toughness.

The behavior of these resins under compression is shown in Figure 14. They flow under initial application of load. After a short time there is no further change, unless the load is changed or the temperature raised.

"Teflon" tetrafluoroethylene resins have an appreciable degree of elasticity, and have a perfect plastic memory, or tendency to return to their original shape when heated. When a deforming load is removed, with no change in

TEMPERATURE, °C. °F.		WEIGHT LOSS, %/hour
204	400	0.0002 (1)
260	500	0.0002 (1)
316	600	0.0002 (1)
360	680	0.001 (2)
390	734	0.006 (2)
420	788	0.09 (2)

(1) Test conducted on granular molding powder.
(2) Test conducted on molded sheet.

TABLE 2—Weight loss of "Teflon" tetrafluoroethylene resins at various temperatures

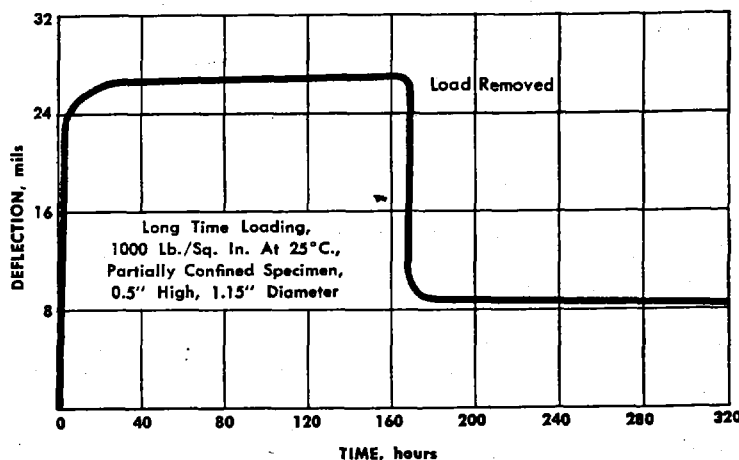
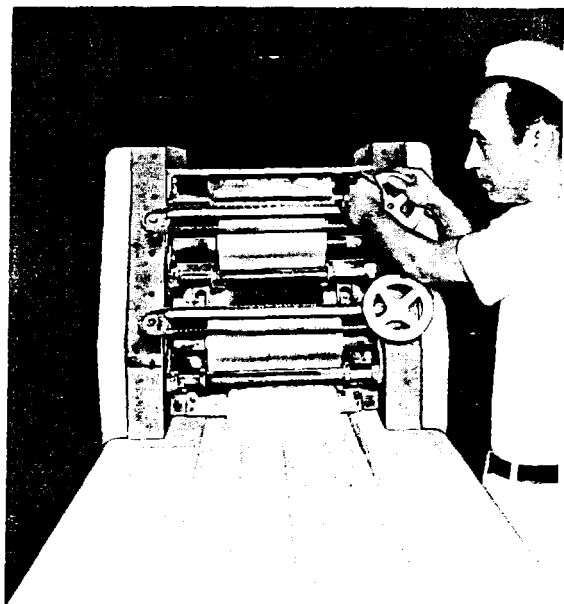


FIGURE 14—Typical compressive stress deformation data for "Teflon" tetrafluoroethylene resins

temperature, there is some recovery, as shown in Figure 14, page 15. If the temperature is raised after removal of load, more complete recovery is effected, and heating to the transition temperature (620°F.) will restore the original dimensions. (This property of plastic memory is used to advantage in making tight joints between these resins and metal. A component made of a "Teflon" tetrafluoroethylene resin is pressed into a metal assembly at a low temperature in such a manner that there is some deformation of the component. As the temperature is increased and the component of "Teflon" tetrafluoroethylene resin tends to recover its original shape, a tight joint is produced.)

"Teflon" tetrafluoroethylene resins can be "oriented," as indicated by the fact that they do not recover completely when a deforming load is removed (at normal temperatures). Whether deformed by a tensile or compressive force, internal stresses are introduced that will remain unless relieved by heating. Such internal stresses, often termed orientation, have a marked effect on the physical properties of these resins. This is typified by molded sheets that are cold-rolled to increase length and width with a corresponding reduction in thickness. Rolling of sheet stock increases tensile



strength and reduces the tendency to deform under compressive load. On the other hand, when sheets processed in this manner are heated, without physical restraint, they shrink in length and width and increase in thickness, because of the stress-relief that takes place.

Any article of "Teflon" tetrafluoroethylene resins may contain internal stresses. To obtain maximum dimensional stability, it is necessary to remove such stresses by heating at a temperature above that which will be encountered in service, before finishing to the final dimensions.

Friction Properties — "Teflon" tetrafluoroethylene resins have an extremely low coefficient of friction. Coefficients of friction as low as 0.04 have been measured at high loads. The coefficient of friction is independent of temperature in the range of 77°F. to 572°F. However, a drop in the coefficient of friction is quite apparent as the temperature is reduced to below the room temperature transition point (about 70°F.) of these resins.

In actual practice, thin films of a "Teflon" tetrafluoroethylene resin are transferred to surfaces sliding or rotating against it until the surface itself is coated with the resin. Thus, the condition becomes one of a "Teflon" tetrafluoroethylene resin sliding against a "Teflon" tetrafluoroethylene resin.

The static coefficient for these resins is equal to the dynamic value. Hence "Teflon" tetrafluoroethylene resins do not exhibit a stick-slip type of motion.

Further, the value for tetrafluoroethylene resins is lower than those of graphite and molybdenum disulfide (0.09-0.12). Consequently, conventional low-friction additives such as these materials are not needed to enhance the friction properties of "Teflon" tetrafluoroethylene resins.

Non-Adhesive Property — A unique property of "Teflon" tetrafluoroethylene resins, related to their low friction characteristics, is the fact that few materials tend to stick to their surface. This property is utilized in a variety of opera-

tions in which sticky materials are handled, as shown in the illustration on page 16.

Chemical Properties—"Teflon" tetrafluoroethylene resins have practically universal chemical inertness. Of the chemicals encountered in commercial practice, only alkali metals such as sodium, halogens such as fluorine and some halogen compounds show any sign of attack on these resins. Even with these, special conditions such as elevated temperatures or pressures or both are required for a noticeable effect. "Teflon" tetrafluoroethylene resins have been tested in many boiling solvents, including a variety of halogenated hydrocarbons, ketones, esters, and alcohols, without swelling or change in weight. It has been immersed in boiling aqua regia, and in hydrofluoric, nitric, and sulfuric acids with no change in weight or properties. It is equally resistant to attack by alkalis in all concentrations. Fluorine and chlorine trifluoride will react with it at elevated temperatures and pressures. Although tetrafluoroethylene resins are successfully used in chlorine and bromine service, under certain conditions the halogens and halogenated compounds may affect them.

In addition to its outstanding chemical inertness, tetrafluoroethylene resins are relatively impermeable to many chemicals. The permeability of films of "Teflon" tetrafluoroethylene resins to a number of compounds is given in Table 3. These permeability values are very low. Metal coated with a thin layer of a "Teflon" tetrafluoroethylene resin is considerably superior in chemical resistance to uncoated metal. However, on long immersion, materials such as hydrochloric acid may diffuse through the film and attack the metal substrate. In the case of thick coatings, the rate of permeability is so low as to be negligible.

The permeability property of tetrafluoroethylene resins is sensitive to their density or crystallinity. Table 3 gives permeability rates at 30°C. for samples of low void content of both low and high density. Some of these data have been extrapolated to correct for crystallinity and thickness.

TABLE 3—Permeability data on "Teflon" tetrafluoroethylene resins

TYPICAL PERMEABILITIES		
Gas or Vapor	Permeability, gm./100 sq.in./day (corrected to 1 mil thickness)	
	Specific gravity of "Teflon" tetrafluoroethylene resins	
	2.14	2.22
nitrogen, 86°F.	1.1	0.13
air, 86°F.	1.5	0.2
carbon dioxide, 86°F.	10.0	0.8
hydrogen chloride, 86°F.	0.03	0.004
benzene, 167°F.	0.5	0.07
steam, 334°F.	140	15
Liquids at Room Temperature	Permeability, gm./100 sq.in./day* (corrected to 1 mil thickness)	
acetic acid, glacial	0.33	
nitric acid, 70%	0.45	
hydrochloric acid, 37%	1.5	
benzene	0.2	
water	0.3	

*"Teflon" tetrafluoroethylene resins densities unknown.

Electrical Properties—The electrical properties of "Teflon" tetrafluoroethylene resins are exceptional. Their dissipation factor is less than 0.0003 over the entire spectrum measured to date, 60 cycles to 3,000 megacycles. Their volume resistivity is greater than 10^{18} ohm-cm., even after prolonged soaking in water. ("Teflon" tetrafluoroethylene resins have less than 0.01% water absorption by A.S.T.M. test.) Their surface resistivity is greater than 10^{17} ohms/sq. even at 100% relative humidity.

Tetrafluoroethylene resins also have excellent arc-resistance. On exposure to an arc, material made of the resins is decomposed to a vapor which leaves no carbonized path, regardless of time of exposure to the arc.

Short-time dielectric strengths are high. These values range from 500-4,000 volts per mil, depending on thickness. However, recommended working stresses are in the range of 50-100 volts per mil, typical voltages used in motor and generators.

The electrical properties of "Teflon" tetrafluoroethylene resins are essentially unchanged

at temperatures up to at least 480°F.

Other Properties—"Teflon" tetrafluoroethylene resins are unaffected by either outdoor weathering or moisture. Samples exposed in Florida for over ten years are completely unchanged. The water-absorption of these resins by A.S.T.M. test is less than 0.01%.

"Teflon" tetrafluoroethylene resins are non-flammable.

Safety Precautions—Because of its excellent heat-stability, the electrical and mechanical properties of "Teflon" tetrafluoroethylene resins are not degraded by the high temperatures to which they may be subjected during normal processing operations and in use. However, these temperatures often exceed the point at which small quantities of gaseous decomposition products are evolved. Some of these gases are harmful, and must be eliminated by adequate ventilation. This is so simple and effective that very few problems resulting from the heating of these resins are encountered today.

Animal feeding tests clearly show that "Teflon" tetrafluoroethylene resins are harmless when taken internally in reasonable quantities. Other animal tests have shown that they do not produce skin irritation. These laboratory results are substantiated by the fact that no such cases arising from the handling of these resins during the 18-year history of its development, manufacture, and use, are known to the Du Pont Company.

Dust from "Teflon" tetrafluoroethylene resins, such as might arise from unheated molding powder, is also innocuous.

However, when tetrafluoroethylene resins are heated above 400°F., small quantities of harmful compounds are given off. Consequently, adequate ventilation must be provided at such temperatures.

Tetrafluoroethylene resins are extremely stable to heat, as shown in Table 2, page 15, which gives the weight lost by granular molding powder at various temperatures. The weight loss of tetrafluoroethylene resin extrusion powders is still small, but somewhat

higher than that of the granular material. Sheets and other items molded from these powders show slightly lower losses, because of the lower surface area afforded by molded articles. The pyrolysis of tetrafluoroethylene resins does not become rapid until the temperature exceeds 735°F.

Precautions. During the processing of "Teflon" tetrafluoroethylene resins, safety precautions should be observed in any sintering operation, and in any incidental local heating of these resins, such as may occur during machining operations with high-speed tools, the grinding of metal parts coated with them, or the sawing of sheets. In such operations, exhaust ducts must be located over the equipment. In machining operations, water-cooling is also advisable. Exhausts must have sufficient suction to eliminate the possibility of any cross-draft from open doors or windows. In addition to exhaust ventilation directly over the processing machinery, ventilation should also be provided in the rooms housing the equipment. A typical good installation would be one in which 8,500 cu.ft. of air per minute is provided to a room in which 25 pounds of the resins are processed per hour. Proper education of operating personnel is also imperative.

One further point deserves consideration. It has been pointed out that dust from unheated tetrafluoroethylene resins is, by itself, innocuous. There is the possibility, however, that this dust, or dust from machine turnings, etc., can contaminate cigarettes or other forms of smoking tobacco carried in the pockets of operating personnel. If this should happen, the polymer would be decomposed when the tobacco was smoked, and the fumes would be inhaled. It is suggested that the carrying of cigarettes or tobacco into areas where they could become contaminated with these resins should be prohibited. Since workers with tetrafluoroethylene resins on their hands could transfer this to cigarettes in smoking, they should be advised to wash their hands before smoking.

Further details on health hazards involved in heating "Teflon" are given in Polychemicals Department Information Bulletin No. X-59b.

Use of Additives with "Teflon" **tetrafluoroethylene resins**

The value of "Teflon" tetrafluoroethylene resins in some applications can be considerably enhanced by the use of additives. Such modification improves certain mechanical properties of these resins, and permits compositions based on them to be tailored to a wide variety of chemical, mechanical, and electrical applications.

In general, "Teflon" tetrafluoroethylene resins can be compounded to increase these properties:

- resistance to deformation under load by a factor of 10,
- resistance to wear by rotating shafts, by as much as 500 times,
- stiffness by a factor of 4 to 5,
- thermal conductivity by a factor of 5 to 10,
- compressive strength by a factor of 3 to 4,
- hardness by about 10%.

Furthermore, the modified compositions retain these outstanding properties of uncompounded "Teflon" tetrafluoroethylene resins:

- low coefficient of friction,
- heat-resistance (up to 500°F.),
- excellent outdoor durability,
- non-flammability,
- zero water-absorption,
- excellent electrical properties (at low additive loadings),
- high flexural strength.

Elongation and impact strength of tetrafluoroethylene resins are adversely affected by the addition of modifiers, but in most instances these changes do not impair the usefulness of the product.

The modified compositions can be molded and extruded in the same equipment used for uncompounded resins.

Commercial uses of compounded "Teflon" tetrafluoroethylene resins include pump impellers and bearings; liners for plug valves used in steam lines; valve seats and packings; textile-machinery parts ("saddle" bearings); resistors; mounting boards for electronic and electrical parts; and pipe.

Additives — Any material which can tolerate

TABLE 4—Typical additives suitable for use with "Teflon" tetrafluoroethylene resins

MATERIAL	TYPE	SUPPLIER
Asbestos	7M Canadian—fines	Raybestos Manhattan Company New York, New York
Blue asbestos	Blue African—long staple	Raybestos Manhattan Company New York, New York
Bronze	MO-8802 powder	Metal Disintegrating Co., Inc. Elizabeth, New Jersey
Calcium fluoride	technical fluorspar	Grasselli Chemicals Department Du Pont Company Wilmington, Delaware
Coke flour	GC calcined petroleum coke flour; 55-65% through 200 mesh	National Carbon Division Union Carbide and Carbon Corp. New York, New York
Glass fiber	chopped, milled 1/32"	Owens-Corning Fiberglas Corp. Philadelphia, Pennsylvania
Graphite	GP-38 Acheson, 98.5% through 200 mesh	National Carbide Division Union Carbide and Carbon Corp. New York, New York
Zircon	"G" milled (gray white); fineness less than 44 microns	Titanium Alloy Mfg. Div. National Lead Company Niagara Falls, New York

the processing temperatures required for tetrafluoroethylene resins can be used. This temperature requirement eliminates organic additives, but most inorganic materials are sufficiently heat-stable. Types of additives that are generally suitable include metallic copper and bronzes, glass fiber, graphite, coke flour, molybdenum disulfide, clay, talc, silica, asbestos, and calcium fluoride powder. Specific materials that have been used with "Teflon" tetrafluoroethylene resins are listed in Table 4.

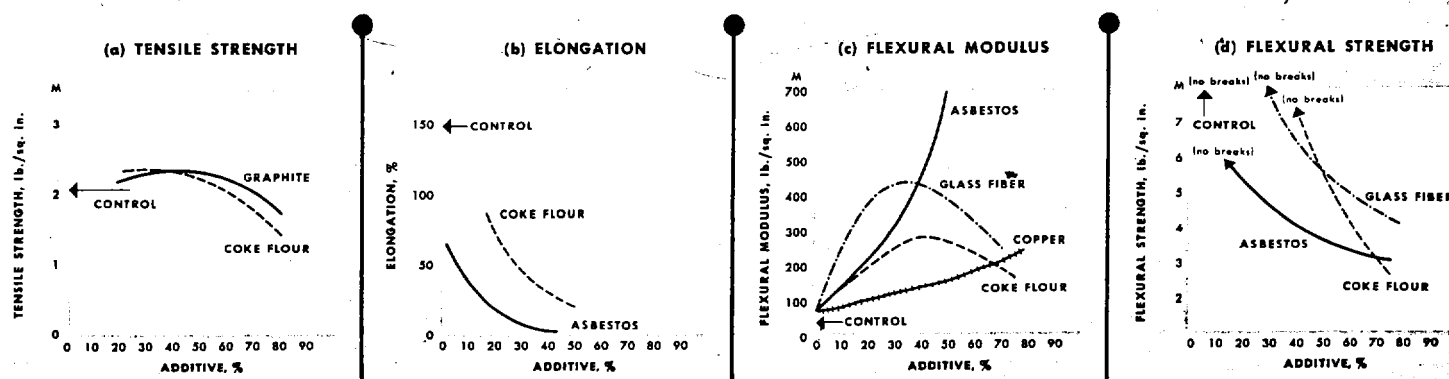
The choice of a specific additive and concentration depends on the needs of the particular application for which the composition is intended.

As a general rule, the additive should be used in the smallest particle size in which it is available, to obtain the maximum physical properties. However, exceptions may be found in the cases of materials of extremely fine particle size.

Properties of Compounded "Teflon" Tetrafluoroethylene Resins

The physical properties of compounded tetrafluoroethylene resins depend on the additive, the amount of additive, uniformity of the blend, and molding and annealing techniques. The data which follow, and the accompanying curves (Figure 15) are typical values, and suggest the range of properties that may be obtained. When comparing properties achieved with different additives, it is important that comparisons be made on stocks having equal volume loadings of additive.

FIGURE 15—Properties of compounded "Teflon" tetrafluoroethylene resins



The tensile strength of the composition is not changed to any great extent with increasing concentrations of additive until high loadings (about 50% by volume, and more) are reached (Figure 15a). Elongation, on the other hand, decreases rapidly with addition of additive (Figure 15b).

Flexural modulus (modified A.S.T.M. D790) increases sharply with increased concentration of additive beyond 10%, reaches a maximum, and then declines (Figure 15c). This property varies appreciably with molding technique; maximum modulus is obtained by baking in the mold.

At proportions of additive generally used, the compositions are too tough to permit measurement of flexural strength by the usual test (modified A.S.T.M. D790). At extremely high loadings, flexural strength decreases as additive content is increased (Figure 15d).

Like elongation, impact strength is decreased with addition of modifier (Figure 15e). In many applications, high impact values are not required; for others, it will be necessary to use low loadings.

Compressive strength is increased considerably by the addition of modifier (Figure 15f).

Resistance to deformation under load is improved to an even greater extent. The following are typical values:

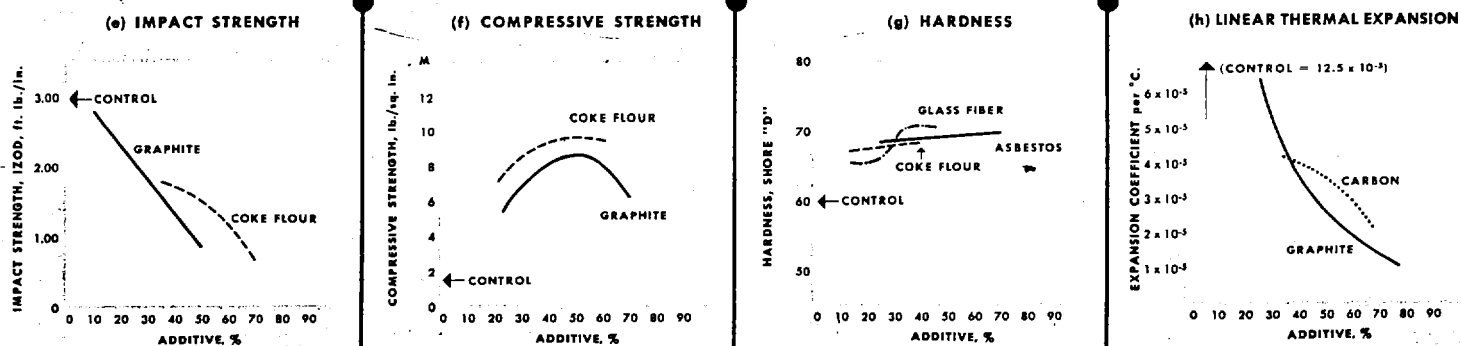
Additive	% Additive (by volume)	% Deformation Under Load 2,000 lb./sq.in. 122°F., 24 hrs.
none	0	25
coke flour	33.3	1—2
coke flour	66.7	0.5—1.3
asbestos	50	0.3
graphite	25	1.7
graphite	50	1.3

Resistance to creep, important in applications in which the "Teflon" tetrafluoroethylene resins are subjected to a sustained load, is improved in a similar manner.

Modified compositions are harder than uncompounded, though the increase is small at lower loadings (Figure 15g). At higher loadings, hardness can be increased substantially.

Although the values for the coefficient of friction vary slightly depending on both additive and loading, these differences have little practical significance at usual levels. Consequently, compounded products can be considered as having the same low friction characteristics as the unmodified "Teflon" tetrafluoroethylene resins. No scoring of steel shafts occurs even with hard materials such as glass fibers, though more severe abrasives such as zircon and carborundum should be avoided.

The most striking advantage of modified



compositions over uncompounded "Teflon" tetrafluoroethylene resins is in resistance to wear. Stocks modified with silicates, chopped glass fibers, molybdenum powder, and graphite show particularly good wear-resistance. Some typical values are given in Table 5.

The linear coefficient of thermal expansion is lowered considerably by the addition of about 25-30% modifier (Figure 15h). Values approaching those of steel and copper are possible with very high modifier content. This property appears to be more dependent on the loading than on the particular additive used.

The addition of modifiers increases the thermal conductivity of "Teflon" tetrafluoroethylene resins to an appreciable degree. The magnitude of this change depends on the nature of the additive, as well as the amount. The following are typical values:

Additive	% Additive (by volume)	Thermal Conductivity B.T.U./hr./sq.ft./ °F./in.
none	0	1.7
coke flour	66.7	6.6
graphite	50	9.5
graphite	74	19.5
asbestos	50	4.2
copper	50	7.5

Excellent electrical properties are obtained at lower concentrations of additive. Typical data on power factor, dielectric constant, and volume resistivity are given in Tables 6 and 7.

The water-absorption of compounded "Teflon" tetrafluoroethylene resins is negligible, depending on the nature of the additive. In many instances water-absorption is not detected by standard tests, even after 24-hour immersion in boiling water.

The density of compounded "Teflon" tetrafluoroethylene resins varies directly with the density of the additive. Inasmuch as porosity contributes to low density, a high density is a good measure of the quality of a molding. Annealing will, of course, increase density until the maximum value is attained.

TABLE 5—Wear rate of compounded
"Teflon" tetrafluoroethylene resins

ADDITIVE (1)	RATE OF WEAR, mg./hr. (2)
none	0.74
glass fibers plus pigment	0.0015
graphite	0.0015
copper	0.032
molybdenum disulfide	0.038

- (1) Commercial products containing 15-25% additive by weight.
(2) White, H. S., National Bureau of Standards Report No. 2882 (October 1953). Bearings 1/2 inch long x 1/4 inch I. D.; run on Type 303 stainless steel shafts, 0.25 inch in diameter, clearance of 0.002 inch on diameter; 2,000 lb./sq. in.; room temperature; 150 r.p.m.

TABLE 6—Electrical properties of compounded
"Teflon" tetrafluoroethylene resins

ADDITIVE	% ADDITIVE (by volume)	POWER FACTOR, 1000 cycles	DIELECTRIC CONSTANT, 1000 cycles
none	0	<0.0003	2.0
coke flour (1)	1	0.001	2.4
powdered glass	50	0.0032	4.75
quartz (1)	50	0.0008	3.65
iceberg clay (2)	50	0.05	
talc (3)	50	0.0004	4.41
titanium dioxide (4)	50	0.05	
glass fiber	25	0.0019	

- (1) 100-200 mesh; C. H. Chrystal Co., New York, N. Y.
(2) Burgess Pigment Co., Paterson, N. J.
(3) Whittaker, Clark, and Daniels, New York, N. Y.
(4) "Ti-Pure" L, Pigments Department, Du Pont Co., Wilmington, Del.

TABLE 7—Volume resistivity of compounded
"Teflon" tetrafluoroethylene resins

ADDITIVE	% ADDITIVE (by volume)	VOLUME RESISTIVITY, ohm-cm.
none	0	>10 ¹⁵
graphite	50	87
graphite	75	0
coke flour	66.7	0
asbestos	50	2 x 10 ¹²
copper	50	2 x 10 ⁵
glass fiber	25	2 x 10 ¹³

Standard Products made of "Teflon" tetrafluoroethylene resins

A number of processors are equipped to manufacture stock or custom-made items from "Teflon" tetrafluoroethylene resins. Standard forms made from these resins and available commercially include molded parts, tape, sheets, rods, cylinders, tubes, film, coated fabrics, wire, enamels and finishes.

Tape—"Teflon" tetrafluoroethylene resins are converted into tape by a variety of processes. Methods by which tape is made, thicknesses available, physical appearance, and form of the resin used in each case are listed in Table 8, page 24.

Colored tapes are made from a tetrafluoroethylene resin for use where identification is necessary. A full range of colors satisfactory for JAN Specifications is available. Electrical properties of the colored tapes are the same as those for uncolored tape.

Sheets, Rods, Cylinders—In cases in which volume of production or other factors do not warrant molding, parts may be machined from stock shapes of "Teflon" molding powders, such as sheets, rods, and cylinders. These are available commercially in a variety of sizes and thicknesses.

Coated Fabrics and Laminates—Glass fabric coated with "Teflon" dispersion is supplied by the Fabrics Division of the Du Pont Company and other sources. This product is of particular importance in certain applications in the electrical field, since it provides better mechanical strength and resistance to cut-through than unsupported tape. Sheets of glass fabric coated with "Teflon" dispersion are available in thicknesses of 3 to 10 mils.

Laminates of glass fabric coated with "Teflon" dispersion are used where extra rigidity and strength are needed in relatively thick sections.

Finishes—Finishes made from a "Teflon" tetrafluoroethylene resin are supplied by the Finishes Division of the Du Pont Company. They have proved particularly successful in non-

TABLE 8—Tape made from "Teflon" tetrafluoroethylene resins

PROCESS	FORM OF "TEFLON"	DESCRIPTION	THICKNESS, mils
casting	aqueous dispersion	colorless, transparent	0.25 to 4
skiving	molding powder	white, translucent to opaque	1 to 125
extrusion (compounded)	extrusion powder	bluish white, transparent to translucent	4 to 40
calendering	molding powder	bluish white, transparent to translucent	2 to 20
coating of glass fabric	aqueous dispersion	tan, opaque	3 to 14

adhesive applications such as coatings on bread pans, cookie molds, rubber molds, and glue-dispensing equipment. The application of these finishes to metal and other surfaces requires a specialized technique, and custom-finishing services are offered by a number of companies.

Wire enamels are also supplied by the Finishes Division of the Du Pont Company. They are applied to wire by dip coating and sintering operations. Extremely thin coatings are obtainable in this manner.

Coated Wire—The method of applying a

"Teflon" tetrafluoroethylene resin to wire depends to a large extent on the thickness of insulation desired. The full range of wall thicknesses required by the wire and cable industry can be obtained by a variety of methods, as listed in Table 9.

In many applications, especially in the case of cable, the construction of the insulation includes glass braid, metal sheathing, or even a semi-conductive tape. The use of such materials in conjunction with "Teflon" molding and extrusion powders provides increased mechanical strength, resistance to cut-through, and shielding effects.

METHOD OF APPLICATION	FORM OF "TEFLON" USED	INSULATION THICKNESS, mils
dip coating	enamel, made from aqueous dispersion	up to 5
extrusion (compounded)	extrusion powder	8 to 50
calendering	molding powder	15 to 100
ram or screw extrusion	molding powder	60 to 500
tape wrapping	tape, made by a variety of methods (Table 8)	4 and up

TABLE 9—Wire and cable insulated with "Teflon" tetrafluoroethylene resins

Fabricating Techniques

Machining—Articles made of "Teflon" tetrafluoroethylene resins can be readily machined to close tolerances, using standard equipment and techniques. Machining is particularly adaptable to standard shapes made of "Teflon" tetrafluoroethylene resins, such as rods, cylinders, and sheets, available commercially.

General Information. For best results, cutting tools of high-speed steel, ground to produce minimum drag, should be used with "Teflon" tetrafluoroethylene resins. Because of the material's toughness and resiliency, it is most important that tools be kept sharp, and that vibration of machinery be avoided.

The use of coolants such as water or soluble oils will permit higher cutting speeds, though the use of such coolants is generally not necessary to produce work of good quality.

The thermal expansion of "Teflon" tetrafluoroethylene resins is high (several times that of metals). Therefore, for close tolerances, all critical measurements should be made when the piece is at room temperature. Furthermore, since these resins undergo a crystalline transition at about 66°-70°F., their volume changes about 1.5% at this temperature. This fact must be considered in making measurements. It is recommended that measurements be made at a temperature above 70°F. (e.g., 77°F.).

Sawing. Conventional equipment, including band saws, jig saws, and table saws, can be used without modification for sawing articles made of "Teflon" tetrafluoroethylene resins. Band saws and jig saws give high cutting speeds, but tend to leave rough surfaces. A conventional table saw equipped with hollow-ground metal-cutting blades or blades made especially for use with plastics will produce a smooth cut.

The use of a coolant is helpful in sawing articles of a "Teflon" tetrafluoroethylene resin. The production of webs or strings is evidence of overheating and indicates the need of a coolant.

Drilling. Parts of "Teflon" tetrafluoroethylene resins can be drilled satisfactorily with conventional twist drills. Special drills, designed for use with plastics, are available from

drill manufacturers. These drills have deep flutes that are highly polished to facilitate removal of chips. Too, some types have much longer flute leads than conventional drills. The use of these special drills for production work is recommended because of the higher drilling rate made possible.

Of course, drilling equipment must be in good condition if accurate holes are to be obtained. Loose spindle bearings or bent or poorly sharpened drills will give inaccurate results with "Teflon" tetrafluoroethylene resins, as with any other material.

The highest speed that will not cause burning or "gumming" should be used, with a slow, uniform feed, to produce a smooth hole of uniform diameter. Chips should be removed at frequent intervals by withdrawing the drill from the work to permit clearing of the hole. In deep holes, the application of cutting oil or other coolant will prevent sticking of the chips.

Reaming. Articles made of "Teflon" tetrafluoroethylene resins can be reamed with conventional types of reamers to produce holes with good finish and accurate dimension. Reamers of the expansion type are preferred. Because of the resiliency of "Teflon" tetrafluoroethylene resins, cuts made with a fixed reamer tend to be undersize. It is almost impossible to remove as little as 0.002-0.003 inch when reaming. Although the reamer will pass through the hole, no stock will be removed, and the hole will remain at the original dimension after the reamer is removed. At least 0.010 inch should be removed by the final reaming if a hole of correct size is to be produced.

Threading and Tapping. Parts of "Teflon" tetrafluoroethylene resins can be threaded or tapped with conventional equipment. On automatic or semi-automatic equipment self-opening dies with high-speed chasers can be used. The use of a lubricant or coolant is desirable when threading or tapping articles made of "Teflon" tetrafluoroethylene resins, but is not always necessary.

Threads may be cut in parts of "Teflon" tetrafluoroethylene resins using a lathe with conventional single-pointed tool. As with met-

als, several successive cuts of 0.005-0.010 inch should be made. The finish cut should not be less than 0.005 inch because of the resiliency of the material. When threading long lengths of rod stock, it is necessary to use a follow rest or other support to prevent the work from slipping away from the tool.

In production tapping, it is frequently desirable to use a tap 0.005 inch oversize unless a self-locking thread is desired.

Turning. Articles of "Teflon" tetrafluoroethylene resins can be turned quite easily on any standard metal-working lathe. No special precautions need be observed, although, as in other machining operations, tools should be very sharp. Bits should be ground as for yellow brass or bronze and should have minimum drag. Since "Teflon" tetrafluoroethylene resins tend to produce a continuous chip, which may cause trouble by wrapping around the work, it is helpful, when possible, to grind a chip breaker on the bit to overcome this. Otherwise, it is necessary to cut the chip loose at the end of each pass.

High rotational speed with a fine feed will produce a smooth finish, if the tool is properly sharpened. Use of a coolant will permit higher speeds and feeds to be used without causing the surface of the work to soften.

Blanking and Punching. Small flat parts such as washers, 1/16 inch or less in thickness, can often be produced more economically by punching or stamping from sheet stock than by injection molding. Conventional dies are used in either hand- or power-operated punch presses. With well-made dies, articles of "Teflon" tetrafluoroethylene resins may be blanked or punched cleanly at high speed. If cracking occurs, it can usually be overcome by preheating the strip or by soaking it in water.

Forming—Tape and sheet stock made from "Teflon" tetrafluoroethylene resins can be formed by drawing between male and female dies. Cold forming will be adequate in many cases, though preheating will be helpful when extensive drawing is attempted. A draw of

depth equivalent to one-half the diameter of the original sheet can be obtained quite readily.

Bonding—Articles of "Teflon" tetrafluoroethylene resins can be successfully bonded to themselves, or to other materials in a variety of ways. In the case of thin tapes or films (less than 20 mils thickness) heat-sealing is frequently successful. This method involves a short heat cycle with mild contact pressure.

For thicker sections (up to 120 mils) a bonding aid is also required. Two materials which have been found successful as a bonding aid are (1) a film of unsintered tape made from a tetrafluoroethylene resin, and (2) a paste made from a tetrafluoroethylene resin and a fluorocarbon oil.

In addition, "Teflon" tetrafluoroethylene resins can be bonded with conventional adhesives after suitable surface treatment.

Bonding with Unsintered Tape. Unsintered tape of "Teflon" tetrafluoroethylene resins with a thickness of 0.010 inch is very satisfactory for this technique. It should be placed between the pieces to be bonded and clamped. The area is then heated to 650°F-720°F. and allowed to cool immediately with the clamps in place.

Advantages of this tape method of bonding include cleanliness and precision. There is no extrudation accompanied by dripping or smoking, as may occur with the paste flux method.

Bonding with a Fluorocarbon Paste. The process of bonding articles made of "Teflon" tetrafluoroethylene resins to other articles made of "Teflon" tetrafluoroethylene resins is greatly accelerated by the presence of liquid

fluorocarbon. A suitable bonding aid is a paste consisting of 35 parts by weight "Teflon" molding or extrusion powder and 65 parts "Fluorolube"¹ LG, a commercially available fluorinated hydrocarbon.

In making a lap joint, a thin coating of the paste flux is applied to one surface, and the second piece is clamped securely into position. The area to be bonded is then heated to a temperature of 650°F.-720°F., and immediately allowed to cool with clamps in place.

It is essential to heat the bond area from both sides at the same time, and electrical strip heaters have been found satisfactory for this.

Bonding With Conventional Adhesives—Various processors have developed their own patented procedures for preparing articles of "Teflon" tetrafluoroethylene resins having special surfaces to which conventional adhesives will bond. Conventional adhesives adhere to these treated surfaces. As a result, good bonding strength can be achieved between "Teflon" tetrafluoroethylene resins and wood, glass, steel, aluminum, copper, ceramics, plastics—and, in fact, any material that will bond with an adhesive. This development has opened up new applications where a material with anti-stick qualities and excellent frictional properties is required at elevated temperatures and under severe corrosive conditions. Parts fabricated of "Teflon" tetrafluoroethylene resins will withstand temperatures up to 500°F. However, the adhesive may be the limiting factor at elevated temperatures, and its maximum service temperature should be established before using under these conditions.

¹Registered trademark of Hooker Electrochemical Co., Niagara Falls, N. Y.

Coloring "Teflon" tetrafluoroethylene resins

Pigments can be incorporated into "Teflon" tetrafluoroethylene resins to give a variety of colors. Colored "Teflon" tetrafluoroethylene resin compositions are useful in wire and cable applications for distinguishing individual wires in multi-wire systems; in resistors and capacitors for indication of electrical rating; in other molded electrical and electronic parts for identification purposes; and in the chemical industry for the identification of various pipe and tubing systems.

For all applications in which "Teflon" tetrafluoroethylene resins are sintered, the pigments must be capable of withstanding the sintering temperatures (720°-740°F.). Consequently, these applications usually require inorganic pigments. For the few applications in which "Teflon" tetrafluoroethylene resins are not sintered, pigments of lower heat-resistance can be used.

In many instances, it is important that the other properties of "Teflon" tetrafluoroethylene resins not be altered by the addition of pigment. This can usually be accomplished without difficulty, if the quantity of pigment added does not exceed 2% of the composition. The permissible concentration varies with the properties of the particular pigment. Specific information on the heat-stability, hiding power, and dielectric properties of individual pigments can be obtained from pigment manufacturers. A list of suggested pigments is given in Table 10. Each of these can be incorporated into all forms of "Teflon" tetrafluoroethylene resin.

In all cases, it is important to obtain a homogeneous mixture of the pigment and the "Teflon" tetrafluoroethylene resin. In the case of molding powder, this can best be done by grinding the two materials together in a "Mikropulverizor" (or similar equipment) or at liquid nitrogen temperatures. The latter method appears to give the best results.

The extrusion powder can be colored by grinding the pigment to a particle size of about 0.2-0.5 microns; adding the pigment to the powder in a container; and rolling the mixture on standard jar rolls. The pigment can be

TABLE 10—Pigments suitable for use with "Teflon" tetrafluoroethylene resins.

PIGMENTS	SUPPLIER
"Cadmolith" Yellow No. 00	Glidden Company
"Aqua-Black" Carbon, Black	National Carbon Company
Cobalt Blue No. 10558	Du Pont Electrochemicals Dept.
"Ti-Pure" Titanium Dioxide	Du Pont Pigments Department
"Monastral" Blue	Du Pont Pigments Department
"Monastral" Green	Du Pont Pigments Department

... plus the following colors made by the Ferro Corporation:

F-5891—Maroon	F-6111—Medium brown
F-5892—Dark red	F-6109—Light yellow brown
F-5893—Red	F-2969—Yellow
F-4869—Dark pink	F-5512—Lemon yellow
F-5894—Orange red	F-9658—Green
F-5895—Orange	F-5688—Yellow green
F-5896—Light orange	F-5274—Medium blue
F-5897—Orange yellow	F-5272—Blue green
F-2967—Buff	F-5685—Turquoise
F-6115—Dark buff	F-5278—Light violet
F-6112—Red brown	F-2302—Black
F-6113—Dark yellow brown	F-4708—Black
F-6114—Chocolate brown	F-5073—White

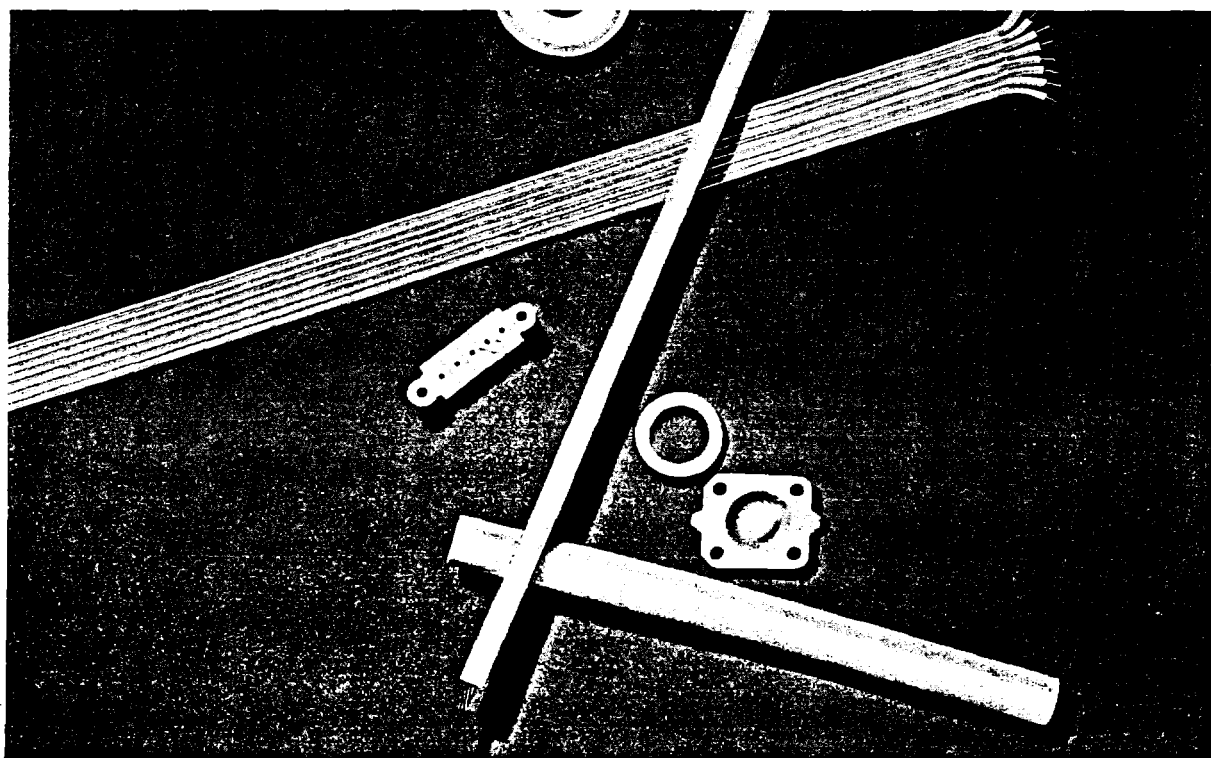
added before, at the same time, or after addition of the extrusion aid, in the case of applications in which the fine powder is to be ex-

truded. When compositions including the extrusion aid are being blended, a sealed container must be used.

Color can best be added to "Teflon" aqueous dispersion if the pigment is first dispersed separately in water containing "Triton"¹ X-100 dispersing agent. The two dispersions are then poured together and blended by slow stirring. Either mechanical or hand stirring can be used, but care should be taken to prevent coagulation from excessive agitation.

In some extrusion applications, the product may be of a solid color; in others a stripe or stripes are preferred. When a stripe is to be made, a wedge is cut from the preform of the natural-colored, compounded "Teflon" tetrafluoroethylene resin, and a wedge of the desired color is inserted. The assembled preform is then placed in the extruder, and the tubing or wire-insulation made in the usual manner. Several stripes can be made in this way. If spirals are desired, a spiral groove is cut in the preform, and a spiral wedge inserted.

¹Registered trademark of Rohm & Haas Co., Philadelphia, Pa.



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