

NRL Report 6039

Hydrophobic and Oleophobic Fluoropolymer Coatings of Extremely Low Surface Energy

Properties and Applications

MARIANNE K. BERNETT AND W. A. ZISMAN

*Surface Chemistry Branch
Chemistry Division*

February 14, 1964

PLEASE RETURN THIS COPY TO:

NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20390
ATTN: CODE 2028

Because of our limited supply you are requested to return this copy as soon as it has served your purposes so that it may be made available to others for reference use. Your cooperation will be appreciated.

PRNC-NRL-20-820



U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

ABSTRACT

A comparison of the critical surface tension of wetting γ_c of new but commercially available polymeric solids has revealed that a group of polyfluoroesters had the lowest values of γ_c of any plastics or other solids yet reported. In order to assess their possible utility in certain new potential naval applications, experimental studies were made on the effect of (a) high humidity and (b) immersion in organic liquids on thin coatings of the two fluorinated polyesters. No changes in coating adhesion to the underlying resin or metal surfaces were found after such exposures, nor were the wettability or other physical properties of the coatings significantly affected. Prevention of spreading by fine instrument oils on surfaces of substances such as stainless steel, sapphire, and Pyrex glass was also investigated by applying the coatings as barriers in the form of narrow circular bands, placing the spreading-oil drops in the uncoated center, and exposing the specimens to the atmosphere at ambient temperatures or cycles between $+50^\circ$ and -20°C . The results show that these polymer coatings will have future usefulness in several new types of applications among which are (a) prevention of liquid penetration in electrical, electronic, and mechanical equipment; (b) parting agents or adhesives for mold release applications; (c) barriers to prevent oil spreading in fine instruments; and (d) reduction of surface electrical leakage.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem C02-10
Subproject RR 001-01-43-4751

Manuscript submitted November 6, 1963

Copies available from Office of Technical Services
Department of Commerce - \$.50

HYDROPHOBIC AND OLEOPHOBIC FLUOROPOLYMER COATINGS OF EXTREMELY LOW SURFACE ENERGY PROPERTIES AND APPLICATIONS

INTRODUCTION

Systematic studies of the effect of chemical constitution on the wetting and spreading of liquids on solids, carried out by Zisman and coworkers (1) over the past fifteen years, have proven that the surface of a solid will exhibit the least adhesion, wettability, and the largest contact angles with liquids when its outermost surface layer is composed of closely packed perfluoromethyl groups. Such a surface has been realized with one type of adsorbed fluorinated fatty acid monolayer, which gave 6 dynes/cm, the lowest recorded critical surface tension of wetting (2). During the past five years, much industrial research on synthesis of novel polymeric fluorinated compounds has been carried on in the U.S.A. with the aim of producing resinous materials having such perfluoromethyl surfaces.

Studies by Bernett and Zisman (3,4) a few years ago showed that several new types of solid polymers produced by the duPont Company have lower surface energies than any previously known polymer, including polytetrafluoroethylene. These materials included various copolymers of tetrafluoroethylene and hexafluoropropylene (HFP) in various molar properties and also a HFP homopolymer. Depending upon the molar properties of the polymer constituents, the critical surface tension of wetting γ_c of the respective copolymer decreased as perfluoromethyl groups in each surface replaced perfluoromethylene groups and reached its lowest value of 16.2 dynes/cm for polyhexafluoropropylene, which in this series presented the highest proportion of perfluoromethyl groups in the surface.

The research effort of the Minnesota Mining and Manufacturing Company in developing a group of new compounds for use in treating fabrics for water-, soil-, and stain-resistance is now well known. The surface properties of these compounds appeared very interesting to us in the light of present knowledge of the relation of wetting and adhesion to surface constitution, and at our request the producer generously made available two unusually pure laboratory preparations of fluorinated polymers for our studies of the wettability and other surface properties. These compounds were an acrylic and a methacrylic polymer, respectively, each containing a linear seven- or eight-carbon perfluoro side chain linked to the polymer backbone by a carboxy group. Our investigation indicated that these perfluoroalkyl side chains are oriented at right angles to the principle axis of the polymer and arranged in close packing so that the surface of the molecule comprises a nearly tight array of perfluoromethyl groups. The result is to impart to these two polymers the lowest critical surface tensions of wetting (11.1 and 10.6 dynes/cm) yet reported for any bulk solid (5). These values of γ_c are in the same range as all but the least wettability of the condensed adsorbed monolayers of perfluoroalkanoic acids (2) and 17-perfluoroalkylheptadecanoic acids (6).

Since such polymolecular plastic coatings are more resistant to rubbing and abrasion than adsorbed monolayers and each of these fluorinated polymers had such a limited wettability, it was recognized that these materials might well have other uses besides the coating of textiles including applications to coatings on mechanical, electrical, or electronic equipment (a) to provide water, oil, or fuel resistance, (b) to reduce surface

electrical leakage, or (c) to serve as adhesive or "nonstick" agents. The copolymers of tetrafluoroethylene and hexafluoropropylene (FEP) are limited for many such uses by the more rigorous surface treatment required for depositing thin, continuous, adherent polymer coatings, since in order to assure good film adhesion, the objects to be coated need a brief baking in an oven or total immersion in a fluidized bed of the hot polymer powder at temperatures above 550° F (7). The fluoropolyesters, however, can be deposited as an adherent film from a solution in a volatile fluorochemical solvent at room temperature.

In order to investigate certain properties of thin coatings made from these fluorinated polyesters, panels made from a variety of plastics or other materials ordinarily used by the Navy as electrical insulation, as well as disks of several types of commonly used metals, were each coated with a polymolecular film of each fluorinated polyester and subjected to a high humidity environment or to immersion in various organic liquids. It was hoped to ascertain whether such exposures affected the adhesion, wettability, or other physical properties of the coating.

EXPERIMENTAL DETAILS

The two fluorinated polymers studied were exceptionally pure experimental compounds supplied by the research laboratory of the Minnesota Mining and Manufacturing Company in the form of a 20% solution in pure xylene hexafluoride. The formulas of the respective monomers are $C_7F_{15}CH_2OOC-C(CH_3)=CH_2$ (polymer A) and $C_8F_{17}SO_2N(C_3H_7)-CH_2CH_2OOC-CH=CH_2$ (polymer S). Each compound studied was cast as a film by pouring a measured quantity of the solution on the smooth surfaces of the test panel; the solvent was evaporated slowly under controlled conditions at room temperature in a dust-free environment followed by an exposure for 24 hours in a clean vacuum oven at 50°C and 30 inches of Hg. The resulting smooth and specular films were from 6 to 9 mils thick, firm and transparent, and were so adherent that only small fragments could be removed from the panel by chipping the coating.

The panels used (Tables 1 and 2) were Pyrex, stainless steel, and each of the following plastics cut into rectangles with surfaces of 1 × 2 inches and thickness of 1/16 to 1/8 inch: Formica (glass epoxy); NELCO 100 (glass epoxy); Taylor Fibre XY-1 (paper-base epoxy); Taylor Fibre XXXP-242 (paper-base phenolic); Bakelite (fiber reinforced); and Bakelite (paper reinforced). Two panels of each material were subjected to different treatments in order to investigate both their hydrophobicity, or contact angle by water, and their organophobicity, or contact angle by oily or other organic liquids. One panel was enclosed for one week in an NRL water-fog chamber (8,9) at 49°C and 100% R.H. (Table 1), and the other immersed at room temperatures for periods of one and four weeks in one of the following organic liquids: hexadecane, paraffin oil, tricresyl phosphate, dicyclohexyl, propylene carbonate, and bis(2-ethylhexyl)sebacate (Table 2). These liquids were all good commercial grades, and all but the paraffin oil and tricresyl phosphate were given an adsorbent treatment with activated gel and alumina before use.

The metals studied were disks (0.75 inch in diameter and from 1/4- to 1/2-inch thick) of No. 302 stainless steel (18-8), Navy brass, and type 24 aluminum. Before coating each disk, the surface was cleaned to remove any organic contaminants and subsequently specularly polished on a rotating cloth wheel using a fine grade of $\gamma-Al_2O_3$ until the clean surface was completely wettable by water. The coated metal disks were immersed at room temperature (20° to 30°C) in each of the organic liquids indicated in Table 3 for two to four months following which the specimens were drained free of liquid and, whenever necessary, were washed with Tide solution and rinsed with freshly distilled water. Equilibrium contact angles of hexadecane and water on the dried surfaces were measured before and after exposure using the slowly advancing sessile drop method by means of a telescope fitted with a goniometer eyepiece (10).

Table 1
Effect of Humidity on Fluorinated Polyester Coatings Covering Various Materials
(After One Week in Water-Fog Chamber at 49° C and 100% R.H.)

Panel	Polymer A ($\gamma_c = 10.6$ dynes/cm)				Polymer S ($\gamma_c = 11.1$ dynes/cm)					
	θ_{Hex} (degrees)		Visual Observation		θ_{Hex} (degrees)		Visual Observation			
	Before Exposure	After Subsequent Drying*	Before Exposure	After Subsequent Drying*	Before Exposure	After Subsequent Drying*	Before Exposure	After Subsequent Drying*		
Pyrex	74	68	74	opaque	clear	73	67	71	opaque, orange peel	clear, orange peel
Stainless Steel	74	69	74	opaque	almost clear	-	-	-	-	-
Formica (1/8 glass epoxy)	74	74	-	clear	-	73	73	-	somewhat dull and pitted	-
Taylor Fibre XY-1 (paper base epoxy)	74	74	-	unaffected	-	73	73	-	somewhat pitted	-
Taylor Fibre XXXP-242 (paper base phenolic)	74	74	-	unaffected	-	73	73	-	unaffected	-
Bakelite (fiber reinforced)	74	74	-	unaffected	-	73	73	-	unaffected	-
Bakelite (paper reinforced)	74	74	-	unaffected	-	73	73	-	unaffected	-

*Exposure followed by drying in vacuum oven for 72 hours at 50° C.

Table 2
Effect of Immersion in Organic Liquids on Fluorinated Polyester Coatings Covering Various Materials
(After One and Four Weeks at 20° to 30° C)

Organic Liquid	Panel	Polymer S ($\gamma_c = 11.1$ dynes/cm)						Polymer A ($\gamma_c = 10.6$ dynes/cm)								
		θ_{Hex} (degrees)*		θ_{H_2O} (degrees)*		Visual	θ_{Hex} (degrees)*		θ_{H_2O} (degrees)*		Visual					
		1 week	4 weeks	1 week	4 weeks		1 week	4 weeks	1 week	4 weeks						
Hexadecane	Pyrex Taylor Fibre XY-1	69	69	114	114	unaffected	69	70	118	118	unaffected	70	70	118	118	unaffected
		-	-	-	-	-	70	70	117	117	unaffected	70	70	118	118	unaffected
Paraffin oil	Pyrex Taylor Fibre XY-1 Bakelite (paper)	-	-	-	-	-	72	71	120	120	unaffected	72	71	120	120	unaffected
		71	71	115	114	unaffected	-	-	-	-	-	72	72	119	118	unaffected
Dicyclohexyl	Pyrex Taylor Fibre XXXP-242	-	-	-	-	-	69	69	118	118	unaffected	71	70	116	116	somewhat pitted
		68	68	114	113	unaffected	71	70	117	117	unaffected	70	70	116	116	somewhat pitted
Propylene carbonate	Pyrex NELCO 100 (epoxy glass)	68	68	114	115	pitted, rough	70	70	120	120	unaffected	71	70	115	115	opaque bubbles on edge
		-	-	-	-	-	70	70	116	116	unaffected	70	70	115	115	slightly pitted
Tricresyl phosphate	Pyrex NELCO 100 Bakelite (fibre)	-	-	-	-	-	70	70	120	120	unaffected	70	70	120	120	slightly pitted
		71	68	112	112	unaffected	-	-	-	-	unaffected	70	70	110	110	slightly pitted
Bis(2-ethylhexyl) sebacate	Pyrex	-	-	-	-	-	70	68	120	120	unaffected	70	68	120	120	slightly pitted
		71	68	112	112	unaffected	70	68	112	112	unaffected	70	68	112	112	slightly pitted

*Before Immersion: θ_{Hex} on polymer S = 73 degrees, on polymer A = 74 degrees.

θ_{H_2O} on polymer S = 118 degrees, on polymer A = 120 degrees.

Table 3
Effect of Immersion in Organic Liquids on Fluorinated Polyester
Coating A Covering Various Metals
(After Four Months at 20° to 30°C)

Organic Liquid	Metal	θ_{Hex} (degrees)*	$\theta_{\text{H}_2\text{O}}$ (degrees)*	Visual
Hexadecane	Stainless steel	73	120	Unaffected
	Aluminum	72	119	Unaffected
	Brass	73	120	Unaffected
Paraffin oil	Stainless steel	73	119	Unaffected
	Aluminum	74	120	Unaffected
	Brass	74	120	Unaffected
Dicyclohexyl	Stainless steel	72	119	Unaffected
	Aluminum	72	120	Unaffected
	Brass	73	119	Unaffected
Propylene carbonate	Stainless steel	73	119	Unaffected
	Aluminum	73	120	Unaffected
	Brass	72	119	Unaffected
Tricresyl phosphate	Stainless steel	73	119	Unaffected
	Aluminum	73	119	Unaffected
	Brass	73	118	Unaffected
Bis(2-ethylhexyl) sebacate	Stainless steel	73	120	Unaffected
	Aluminum	72	120	Unaffected
	Brass	72	119	Unaffected

*Before immersion: θ_{Hex} = 74 degrees.
 $\theta_{\text{H}_2\text{O}}$ = 120 degrees.

RESULTS AND DISCUSSION

Effect of Humidity

The adhesive qualities of the films for any of the panels or disks tested were not affected by exposure to an environment of 100% R.H. and 49°C for one week. Any visible effects on the physical appearance of the films or on changes in the wetting properties are summarized in Table 1. Whereas films cast on hydrophilic surfaces, such as Pyrex, stainless steel, and Formica (glass epoxy), became somewhat pitted or acquired an orange-peel surface, films cast on hydrophobic surfaces, such as Taylor Fibre and Bakelite, remained unaltered. The same films also showed changes in wetting properties; equilibrium contact angles of hexadecane (θ_{Hex}) on polymer film cast on Pyrex or stainless steel were lower by 4 to 6 degrees. When these panels were subsequently dried for 72 hours at 50°C in a vacuum oven (30 inches of Hg), wetting properties were restored to their original state although the physical appearance of the films remained in their pitted or orange-peel state.

Effect of Exposure to Organic Liquids

Table 2 shows the effect on the contact angle of hexadecane (θ_{Hex}) and of water ($\theta_{\text{H}_2\text{O}}$) and on the physical appearance of the coated panels after they had been immersed

in organic liquids for 1 and 4 weeks at room temperatures (20° to 30°C). No change in physical appearance was observed on immersion in nonpolar liquids, such as hexadecane or paraffin oil, and only occasional pitting or opaqueness were noted after prolonged exposure in some polar liquids. Wettability, however, was only slightly affected. The small decrease in the contact angle of hexadecane on all specimens indicated a slight decrease in the oleophobic properties, whereas the hydrophobic properties (as observed by the water contact angle) remained unchanged in some specimens and were slightly decreased in others. All changes in wetting properties occurred within the first week of exposure and remained unaltered the following three weeks.

Grajeck and Petersen (11,12) have reported on the oil- and water-wetting properties of the same family of fluoropolymers when applied as finishes for textiles. They found that the conditions of drying-and-curing had a marked effect on the performance of the textile finish; the highest oleophobicities occurred when the fabric was dried in the air at room temperature while the lowest occurred when the fabric was simultaneously dried-and-cured at 150°C. This behavior was in direct opposition to the hydrophobicity; under the same conditions the hydrophobic contact angle was the lowest after air-drying only, whereas it was the highest after air-drying-plus-curing at 150°C. In our investigation, all specimens were subjected to an air-drying-plus-curing procedure. Our findings are thus in agreement with those of Grajeck and Petersen in those instances where the wettability of the specimens subjected to 100% R.H. was adversely affected.

The Piedmont Section of the American Society of Textile Chemists and Colorists (13), in a recently published study on oleophobic and hydrophobic surfaces, also found that the oleophobicity of fluorochemicals is dependent on curing temperatures. Of several chemically diverse types of textile finishes, the fluorochemical type was the only one which responded with an increase in oleophobicity of the treated textile to an increase in the curing temperature.

Grajeck and Petersen (11) also found that different fabrics, after identical treatment with the fluorochemicals, showed variations in oleophobicity which were again directly opposite to their respective hydrophobicity, but they gave no explanation for the causes of these variations. In our investigation we also found variations in wettability for different substrates. It can be seen in Table 2 that the Pyrex coated with polymer A, after being immersed in tricresyl phosphate, retained the same hydrophobicity as before immersion, whereas the coated Bakelite panel after the same treatment became less hydrophobic; oleophobicity, however, was affected slightly in each case and to the same extent. Analogous results were obtained on Pyrex and NELCO 100 panels immersed in propylene carbonate.

Table 3 presents the results obtained when stainless steel, aluminum, and brass, each coated with a film of polymer A, were immersed for periods of 4 months in various organic liquids. Coatings of polymer A only were prepared, since our previous investigation had indicated that this polymer withstood the test conditions better than polymer S. It can be seen that even after 4 months of immersion the coatings remained practically unchanged with respect to wettability, adhesion, and visual appearance. The polymer coatings in metal substrates are thus unaffected by even those polar organic oils which had some adverse effects on the same coatings on resinous surfaces, emphasizing again the influence of the underlying surface.

Prevention of Oil Spreading

Since these fluorinated polyester coatings have the lowest surface energies of any polymeric material thus far reported, any lubricating oil, fuel, and indeed all common liquids should be unable to spread on it. This property can be utilized to prevent liquid spreading in many devices and it could be made especially useful in fine mechanisms

such as in watches, clocks, and fuses where the lubricating oil needs to be nonspreading. This requirement is essential but so difficult to meet that it greatly limits the lubricant supply and raises the cost. We have recently fully discussed such applications of these fluorinated polyesters (14). Briefly, the oil-barrier coating was applied to the pivot bearing area in the form of a narrow circular band or ring surrounding the oil drop. The advantage of using such a band rather than a disk is that it assures adequate adhesion to the uncoated bearing surface (in a watch, clock, or fuse this would be Pyrex glass, stainless steel, or synthetic sapphire). Figures 1 and 2 show how the small rings of the fluorocarbon resin had for 100 days at 20 to 30°C prevented the spreading on sapphire and stainless steel of various types of lubricating oils or liquids. Some of these oils had

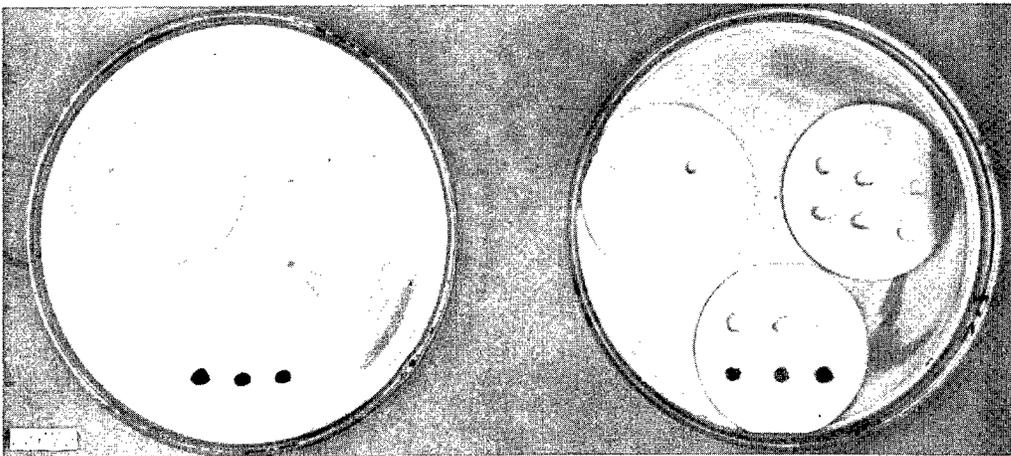


Fig. 1 - Oil drops after 100 days at 20° to 30°C on sapphire. Three drops each of six oils are confined by circular barriers of polymer A (left) and polymer S (right); two barriers on each sapphire plate are void.

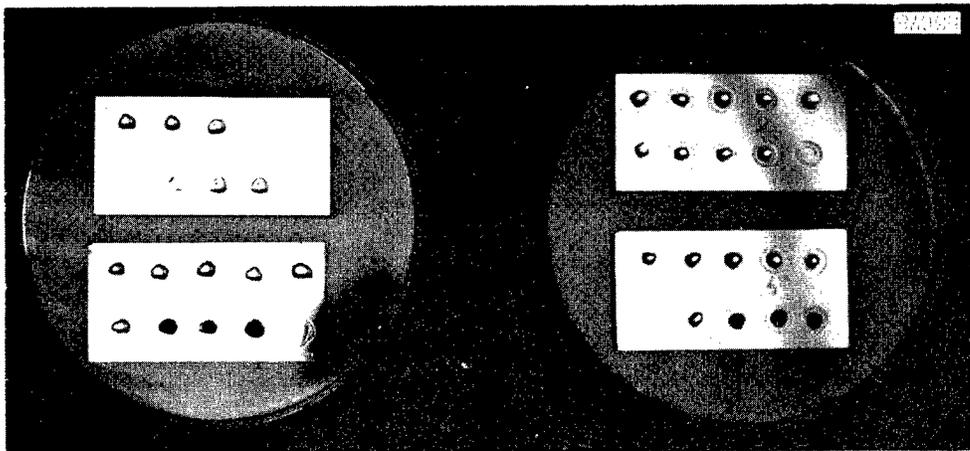


Fig. 2 - Oil drops after 100 days at 20° to 30°C on stainless steel. Three drops each of six oils are confined by circular barriers of polymer S (left) and polymer A (right); one barrier on each steel plate is void.

surface tensions as low as 20.6 dynes/cm and each one would spread completely without the ring of fluorinated polyester. With the exception of one system, each of the oil drops remained confined within its ring-shaped barrier. The one exception was observed with the drop of fluorinated ester bis-(1H,1H,7H dodecafluoroheptyl)3-methylglutarate, which spread over the coating of polymer S only, regardless of the nature of the surface.

Table 4 summarizes the results obtained after these oil drop test specimens had been exposed to room atmosphere at from 20° to 30°C for 100 days, followed by 20 cycles of temperatures between +50°C (80-90% R.H.) and -20°C for 24 hours each (40 days). It can be seen that even after exposure to these severe conditions, none of the unfluorinated oils had spread beyond the circular barrier coating of polymer S, although some of the drops had flattened out; the fluorinated oil in some instances crept beyond the coating entirely.

On sapphire, however, one of each of the three test drops for the sebacate, the mineral oil, and the Ucon oil crept beyond the barriers of polymer A. It was thought that possibly the high humidity produced deleterious effects on the polymer-covered hydrophilic sapphire surface, or that the difference in the coefficient of expansion of sapphire and the fluorinated polyester A was large enough to affect the film adhesion to the substrate. Two more sapphire panels were therefore prepared, one with barriers of polymer A of the same thickness as previously, the other with thinner barriers in order to lessen the possible influence of difference in expansion coefficients. Excess humidity was prevented by placing the panels inside ground-glass enclosed containers. Only the three oils which had spread on the original sapphire surfaces were investigated. After 20 cycles of 8 hours each at +50°C and -20°C, none of the oil drops on either panel had spread (last column of Table 4). It can thus be inferred that the difference in the coefficient of expansion of polymer A and sapphire did not cause spreading of the oil drops in the earlier temperature-humidity cycles. It is not clear yet how the extreme humidity conditions could have caused oil spreading on polymer A; whatever the mechanism, it did not effect polymer S. However, it appears that extremely humid conditions will have to be avoided in order for oil drops to remain confined on sapphire by barriers of polymer A.

Both of the fluorinated polymers studied have the advantage of not being readily dissolved by any of the solvents commonly used to clean such fine mechanisms as watches. Organic solvents such as xylene, petroleum ether, or AMSCO 140 had no adverse effects on polymer A coatings on metal disks after 3 weeks total immersion at temperatures of 20° to 30°C. Proprietary aqueous watch-cleaning solutions containing ammonia detached the coating after prolonged immersion without dissolving it. However, highly fluorinated solvents, such as Freon TF, understandably acted as good solvents for the fluoropolymer; in fact, it is because of the solubility of these polymers in some fluorinated solvents that it is possible to apply the polymer as a coating.

CONCLUSIONS AND RECOMMENDATIONS

The study on two fluorinated polyesters has shown that thin coatings of these polymers on various substrates can be very useful in several applications:

1. On electrical, electronic, or mechanical equipment where resistance to water, oil, or fuel penetration is imperative. Exposures to high humidities or prolonged immersion in organic polar or nonpolar oils do not affect their exceptionally low wettability or their adhesion to smooth surfaces of various metals, plastics, and glass, despite the fact that the appearance of the films changes in some instances from a smooth specular surface to a somewhat pitted or blistered surface.

Table 4
Spreading Behavior of Oil Drops Confined by Ring-Shaped Barriers of Fluorinated Polyester Coatings on Various Materials After Exposure to Temperature Cycles

Spreading Oil	Polymer Coating	After 100 days at 20° to 30°C			After 20 cycles of 24 hours each at +50° (80-90% R.H.) and -20°C			After 20 cycles of 8 hours each at +50° (dry) and -20°
		Stainless Steel	Glass	Sapphire	Stainless Steel	Glass	Sapphire	
Bis(2-ethylhexyl) sebacate	S	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
	A	Unchanged	Unchanged	Unchanged	Flattened	Flattened	Spread beyond coating	
Bis(1H,1H,7H dodecafluoroheptyl) 3 methylglutarate	S	Spread on top of coating	Spread on top of coating	Spread beyond coating	Spread beyond coating	Spread on top of coating	Spread beyond coating	Unchanged
	A	Unchanged	Unchanged	Unchanged	Spread on top of coating	Spread on top of coating	Spread beyond coating	
Silicone DC 200	S	Unchanged	Unchanged	Unchanged	Flattened	Unchanged	Flattened	Unchanged
	A	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Flattened	
Petroleum lubricating oil MS 3042	S	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
	A	Unchanged	Unchanged	Unchanged	Unchanged	Flattened	Spread beyond coating	
Ucon fluid DLB-140E	S	Unchanged	Unchanged	Unchanged	Unchanged	Flattened	Flattened	Unchanged
	A	Unchanged	Unchanged	Unchanged	Flattened	Spread on top of coating	Spread beyond coating	
Nonspreading clock oil 14-L-16	S	Unchanged	Unchanged	Unchanged	Unchanged	Flattened	Flattened	Unchanged
	A	Unchanged	Unchanged	Unchanged	Spread on top of coating	Spread on top of coating	Flattened	

REF ID: A67108

2. As excellent adhesives, or parting agents, for mold release applications, and on equipment or instruments for reducing adhesion of water, oils, and most types of liquids.

3. When applied as barriers to prevent oil spreading or creeping in bearings of fine instruments, such as watches, clocks, fuse mechanisms, or in miniaturized equipment where lubricants have to be confined carefully to avoid deterioration of nearby components or materials. If during their normal use such instruments need to be subjected to abrupt temperature changes from subzero to high temperature in presence of high humidities, the preferred barrier should be the polymer S coating because this polyester withstands such conditions; otherwise polymer A should be used.

4. On electrical and electronic equipment to reduce surface electrical leakage. Coatings of these polyesters should prove very valuable because of their low adhesion for dust, oil, grease, and water. It is therefore recommended that further work should be undertaken to study the surface electrical leakage properties of thin coatings of these polymers at high humidities to assess fully their usefulness as surface insulation coatings.

REFERENCES

1. Zisman, W.A., "Relation of the Equilibrium Contact Angle to Liquid and Solid Constitution," in *Advances in Chemistry Series No. 43*, Washington, D.C., American Chemical Society, 1963
2. Hare, E.F., Shafrin, E.G., and Zisman, W.A., *J. Phys. Chem.* 58:236 (1954)
3. Bennett, M.K., and Zisman, W.A., *J. Phys. Chem.* 64:1292 (1960)
4. Bennett, M.K., and Zisman, W.A., *J. Phys. Chem.* 65:2266 (1961)
5. Bennett, M.K., and Zisman, W.A., *J. Phys. Chem.* 66:1207 (1962)
6. Shafrin, E.G., and Zisman, W.A., *J. Phys. Chem.* 66:740 (1962)
7. Mallouck, R.S., and Thompson, W.B., *SPE J.*, Oct. 1958
8. Baker, H.R., Jones, D.T., and Zisman, W.A., *Ind. Eng. Chem.* 41:137 (1949)
9. U.S. Federal Specification Test Method Std. No. 791, Method 5312.1 (Dec. 15, 1955)
10. Fox, H.W., and Zisman, W.A., *J. Colloid Sci.* 5:514 (1950)
11. Grajeck, E.J., and Petersen, W.H., *Textile Res. J.* 32:320 (1962)
12. Grajeck, E.J., and Petersen, W.H., *Am. Dyestuff Reprtr.* 51:46 (1962)
13. "A Study of Oil- and Water-Repellant Surfaces," *Am. Association of Textile Chemists and Colorists, Piedmont Section, Am. Dyestuff Reprtr.* 52:82 (1963)
14. Bernetti, M.K., and Zisman, W.A., "Prevention of Liquid Spreading or Creeping," *NRL Report 5959*, July 1, 1963; in *Advances in Chemistry Series No. 43*, Washington, D.C., American Chemical Society, 1963