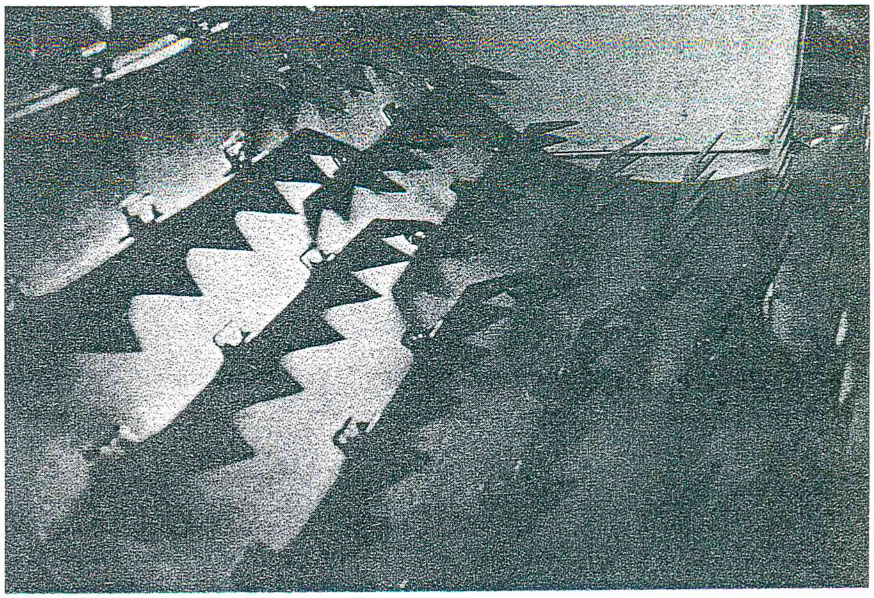
B. Arkles, S. Gerakaris, Machine Design, **47**(6), 103-107, 1975



Sections of a 5½-ft diameter rotary chemical kiln are internally coated with PPS because of its high strength and resistance to chemicals and abrasion at high temperatures. The 25-mil coating was done by Thermech Engineering Corp., Anaheim, Calif., for Agrico Chemical Co.

Apply a function, not simply a finish, with

Powder Coatings that Fight Heat and Chemicals

BARRY ARKLES
Manager, Technical Development

STEPHEN GERAKARIS
Coatings Specialist
LNP Corp.
Malvern, Pa.

TODAY'S COATINGS are called upon to do much more than merely look good. Their role is becoming more and more one of function—to resist heat and chemicals, to insulate, to damp vibration and to otherwise extend the capabilities of a substrate.

Outstanding among the functional coating materials are the high-temperature thermoplastic powders. These 100% solid materials are applied principally by fluidized bed or electrostatic spray. Their use has increased greatly in recent years, both because of their outstanding properties and because of the failure of solvent-based paints to meet health, safety, and ecological standards.

Applications include coating of valves, pumps, reactors, and containers in chemical processing equipment (chemical and heat resistance); components in food processing machinery (heat resistance and release properties); textile equipment (cut-through resistance); microwave ovens (dielectric properties); and business machines (sound and vibration damping).

Materials and Properties

The fluoropolymers currently dominate the area of high-temperature coatings. Fluorinated ethylene-propylene copolymer (FEP), Du Pont's melt-processable grade of Teflon resin, found limited application as a powder over ten years ago. However, adhesion was poor and uniform coverage was difficult to obtain. The latest, most advanced grades of FEP have good adhesion, require no primer, and achieve high builds—over 5 mils per pass—features now common to most of the new high-temperature thermoplastic coatings. But while FEP has the best overall chemical resistance, release characteristics, coefficient of friction, and electrical properties, it is deficient in other areas—notably, wear and cut-through resistance, and permeability.

A number of other thermoplastic powder coatings have recently entered the market; they offer improvements in some properties, but they sacrifice others. Most prominent of these new fluoropolymer resins are ethylene - tetrafluoroethylene copolymer (ETFE), marketed by Du Pont as Tefzel; modified chlorotrifluoroethylene (CTFE), originally introduced by 3M as Kel-F; and ethylene-chlorotrifluoroethylene (ECTFE), sold by Allied Chemical as Halar.

The first nonfluorocarbon to be used successfully in high-performance coatings was chlorinated polyether (Hercules' Penton). While the material performed well, the overall market did not sustain the polymer, and production has been discontinued.

The only other nonfluorocarbon suitable for high-temperature performance applications is polyphenylene sulfide (PPS), introduced by Phillips as Ryton. This material has not only filled the void left by chlorinated polyether, but has extended the total range of powder-coating applications. Although PPS is not intrinsically a good antifriction or release material, grades are available containing modified polytetrafluoroethylene (PTFE) as an internal lubricant. Powder coatings of this compound have a very low coefficient of friction and three to four times the wear life of the base polymer.

Strength and Elongation: Compounds with the lower fluorine contents have the lowest densities and, consequently, provide the greatest coverage. Tensile strength of these materials is also higher, but elongation is low. The extremes, among these materials, are PPS, with 1.34 specific gravity and 10,800 psi tensile strength, and FEP, with a specific gravity of 2.15 and 2,200 psi tensile strength, as shown in Table 1.

The importance of strength and elongation of a coating is questionable, however, since it is the substrate that bears the load. In general, elongation is more important on coated parts subjected to deformation. On the other hand, a coating with higher tensile strength is desirable on parts with sharp edges; the high strength maintains edge integrity and increases creep resistance.

Thermal Properties: Comparison of thermal properties of high-temperature thermoplastic resins is complex. There is no straightforward correlation between polymer structure, melt point, and continuous-use temperature. (Continuous-use temperature is the temperature at which a material retains half of its strength after aging at that temperature for 100,000 hr.) FEP has the highest continuous-use temperature (400 F), but it is very soft and weak at that temperature. (Room-temperature strength is only 2,200 psi.)

ETFE, which has a lower continuous-use temperature, is tougher within its use range, and can withstand higher temperatures on a short-term basis than FEP. PPS performs very well at high temperatures due to a chemical change similar to

Table 1—Typical Properties of High-Temperature Powder Coatings

	Coating Compound					
Property	**FEP**	**ETFE**	**CTFE**	**ECTFE**	**PPS**	**PPS/PTFE**
			Physical, Mechanical			
Specific Gravity	2.15-2.16	1.70-1.71	2.12-2.13	1.67-1.68	1.34-1.35	1.37-1.38
Coverage (sq ft/lb-mil)	89	112	90	114	143	139
Hardness						
Durometer, Shore D	55	75	78	80	86	85
Rockwell R	45	50	85	93	124	122
Impact Strength						
Gardner (in.-lb)						
Face	160	>160	>160	>160	160	160
Reversed	160	>160	>160	>160	160	160
Tensile Strength (psi)	2,200	6,500	4,700	6,600	10,800	10,600
Tensile Elongation (%)	10-20	150-250	100-160	170-200	1-2	1-2
			Thermal			
Melting Point (F)	500-504	522-524	410-412	460-464	505-510	505-510
Max Service Temperature (F)						
Continuous	400	350	325	300	375	375
Short-Term	450	475	390	350	475	475
Thermal Conductivity (Btu-in./hr-sq ft-°F)	1.4	1.65	1.80	1.05	2.00	1.95
Specific Heat (Btu/lb-°F)	0.28	0.46	0.2	0.45	0.25	0.26
Flammability						
Oxygen Index (%)	95	31	80	60	44	46
			Electrical			
Dielectric Strength (V/mil)						
1 mil	7,000	5,000	4,200	4,000	4,500	
4 mils	4,000	3,500	2,300	2,200	2,300	
20 mils	1,700	1,200	1,150	1,100	1,150	
Dielectric Constant at 60 to 2 × 10^7 Hz	2.1	2.6	2.6-2.7	2.6-2.7	3.1-3.3	
Dissipation Factor (10^{-3}) at 60 to 2 × 10^9 Hz	0.2-1.2	0.6-3.0	2.1-9.0	5.0-8.0	4.0-7.0	
Volume Resistivity (ohm-cm)	10^{18}	10^{17}	3×10^{16}	10^{15}	10^{16}	
Arc and Track Resistance (sec)	>160	75	>160	135	160	
			Friction, Wear			
Friction						
Static	0.03-0.04	0.3-0.5	0.4-0.6	0.4-0.6	0.25-0.35	0.15-0.14
Dynamic	0.04-0.06	0.3-0.4	0.2-0.3	0.4-0.5	0.24-0.30	0.13-0.15
Wear						
Weight Loss, Tabor (mg)						
CS 17 Disc, 1-kg Load						
100 cycles	2.2	2.8	2.7	2.4	2.7	1.1
1,000 cycles	14.8	13.4	12.0	11.1	24.0	6.4

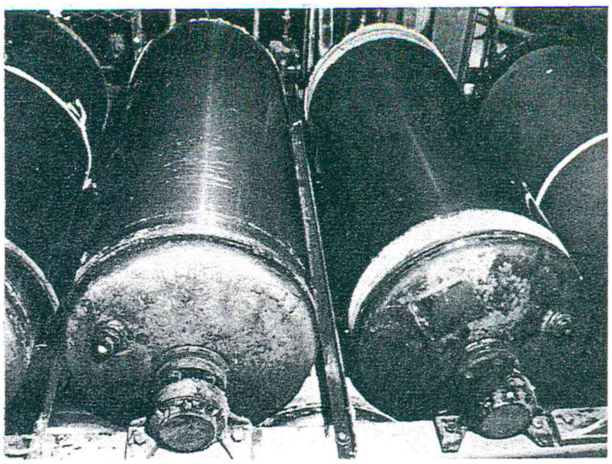
crosslinking that occurs during the cure. PPS has a continuous-use temperature of 375 F, and can withstand short-term exposure to 475 F. ECTFE is at the low end of high-temperature capability range, but it retains toughness and oxidation resistance up to its continuous-use temperature.

Electrical Properties: All of the high-temperature thermoplastic coating resins have excellent electrical properties. FEP is the most outstanding, with a dielectric strength of 7,000 V as measured on a 1-mil film. (However, values of this magnitude are not attainable in materials applied via powder coating techniques; such coatings are much thicker than 1 mil.) FEP has the lowest dielectric constant and the highest volume resistivity of the high-temperature thermoplastic powders. It shares with CTFE the best resistance to arcing or tracking. The only effect of prolonged arc and track resistance tests is the eventual melting of the resins.

In overall electrical properties, ETFE and CTFE are next best. Both provide ample capability for all but the most stringent requirements. A weakness of ETFE is arc and track resistance, at 75 sec. This is good compared to most resins but poor compared to the other high-temperature thermoplastics which resist tracking for more than 120 sec. CTFE, ECTFE, and PPS maintain relatively good dielectric properties, although values are lower and less stable than those of FEP and ETFE. The greatest weakness of ECTFE is volume resistivity; that of PPS is dielectric constant.

Friction and Wear: Frictional and release characteristics of FEP are superior to those of all other thermoplastics. It is the only resin that has a lower static than dynamic coefficient of friction. Release properties of FEP, as determined by critical surface tension (a measure of resistance to wetting), are better than those of any self-supporting material. Its weakness is poor wear resistance, but it does perform better as a coating than as an unsupported member. Unsupported, it wears at twenty times the rate of nylon; as a coating, it wears at only five times that rate, but this is still excessive. ECTFE has the best wear resistance of the fluoropolymers.

All the fluorocarbons have relatively low cut-through resistance; of that group, ECTFE has the highest value. PPS, on the other hand, has excellent cut-through resistance but poor wear resistance.



Dry cylinders (rolls) for textile machinery are coated with ETFE because of its excellent release properties which prevent sizing agents, starches, and dyes from building up on the rolls as the fabric is dried. During operation, the 23 in. diameter rolls are steam heated to as high as 300 F. The ease of application and harder surface of ETFE than the previously used PTFE and FEP dispersions resulted in lower initial cost, and longer service life is expected. Coating was applied for the Hanes Dye and Finishing Co., Inc., by Salem Coatings Inc., Winston-Salem, N. C.

Addition of PTFE to PPS produces a radical reduction in wear rate. This compound has the lowest wear rate of the thermoplastic powder coatings.

Chemical Resistance and Permeability: The high-temperature thermoplastics all have excellent chemical resistance. There are no known solvents for these materials; all other thermoplastics are soluble and are open to attack by various chemicals.

To be effective against chemical attack, a coating must also provide a permeation barrier to protect the substrate. As a class, the high-temperature thermoplastics have extremely low permeability.

Application technique is important in optimizing the chemical resistance of powder coatings. Application of coatings in a minimum of two steps ensures even builds and reduces tendencies to form pinholes. Overcure of the fluoropolymers can reduce chemical resistance; PPS must be fully cured to develop optimum chemical and physical properties.

FEP has the best chemical resistance of any thermoplastic. The only materials known to attack it are molten alkali metals, alkali metal organics, and fluorine. Moreover, chemical resistance is often

Table 2—Permeability of High-Temperature Powder Coatings

	Coating Compound				
Fluid	**FEP**	**ETFE**	**CTFE**	**ECTFE**	**PPS**
Oxygen	750	100	12	25	30
Nitrogen	320	30	5	10	20
Carbon Dioxide	1,670	250	30	100	75
Helium	4,500	900	—	1,100	—
Water	0.32	1.60	0.30	2.66	1.66

Permeability values for the gases are in terms of cm^3-mil/100 in.^{2}-24 hr-atm at 25 C, per ASTM D1434; values for water are in terms of gm-mil/100 in.^{2}-24 hr-atm at 25 C, per ASTM E96.

Table 3—Chemical Resistance of High-Temperature Powder Coatings

Chemical	FEP	ETFE	CTFE	ECTFE	PPS
Acetic Acid, 10%	B	B	B	B	B
Acetic Acid, glacial	B	B	B	C	B
Acetic Anhydride	A	A	C	C	B
Acetone	B	B	B	C	B
Aminoethanol	A	B	X	X	B
Ammonia, dry	B	B	B	B	C
Ammonia, conc (Ammonium Hydroxide)	A	B	B	B	C
Aniline	A	B	C	C	B
Aqua Regia	C	C	B	C	X
Benzene	B	B	B	C	B
Benzaldehyde	B	B	B	B	B
Benzonitrile	A	B	B	B	B
Bromine Water	B	B	B	C	X
Butyl Ether	A	B	C	C	B
Carbon Disulfide	A	A	C	C	B
Carbon Tetrachloride	B	B	X	X	B
Cellosolves	A	B	B	B	B
Chloride Water	B	B	B	C	X
Chloroform	A	B	X	C	B
Chromic Acid	A	C	C	X	X
Crude Oil	B	B	C	C	B
Detergent	A	A	A	B	A
Dimethyl Formamide	B	B	C	C	B
Dioctyl Phthalate	A	A	A	B	B
Dowtherm	A	A	A	B	B
Ether, Diethyl	A	B	C	B	B
Ethyl Alcohol	A	A	A	A	A
Ethylene Diamine	B	C	X	X	B
Ethylene Dichloride	B	B	C	C	C
Ethylene Glycol	B	B	B	B	B
Ethylene Oxide	B	B	C	C	X
Fluorine, dry	X	X	X	X	X
Freon 113	B	B	C	C	B
Fuel Oil	A	A	B	C	B
Gasoline	A	B	B	C	A
Heptane	A	A	B	C	B
Hydrochloric Acid, conc	B	B	A	B	B
Hydrogen Peroxide 30%	A	C	B	C	C
Kerosene	A	A	B	C	B
Ketones	A	B	C	C	B
Methyl Ethyl Ketone	A	A	B	C	B
Methyl Isobutyl Ketone	A	A	B	C	B
Motor Oil	A	A	B	C	B
Naphtha	A	A	B	C	B
Nitric Acid, 70%	B	B	B	C	C
Nitrobenzene	A	A	B	C	B
Nitromethane	B	B	B	B	B
Perchloric Acid	A	B	B	C	C
Perchloroethylene	B	B	C	C	C
Phenol	B	B	C	C	B
Potassium Hydroxide/Methanol	B	B	X	X	C
Silicon Tetrachloride	C	C	B	C	B
Sodium Hydroxide, 50%	A	B	B	C	B
Sodium Hypochlorite Soln	A	B	A	B	B
Stoddard Solvent	A	A	B	C	B
Sulfuric Acid, 10%	B	B	B	B	C
Sulfuric Acid, conc	A	A	B	B	X
Tetrahydrofuran	A	C	C	C	B
Toluene	B	B	B	C	B
Trichlorethylene	B	B	C	C	C
Trifluorotrichloroethane	B	B	C	C	B
Water, tap	A	A	A	B	A
Water, sea	A	A	B	C	B
Xylene	B	B	B	C	B

Key: A—No effect after one month at 300 F.
B—No effect after one month at 200 F.
C—No effect after one month at 100 F.
X—Unacceptable for any exposures.
Values in bold type: Coating thickness of 10 to 15 mils is adequate.
Values in light type: Coating thickness of 15 to 25 mils is recommended.

maintained above melt temperature. Unfortunately, FEP has the highest permeability of the fluorocarbon polymers, Table 2, and the difference becomes greater with increasing temperature. The permeability is limited to small molecules, but water, which is a small molecule, represents over half the environments a coating is likely to encounter in service. Consequently, FEP coatings intended for aqueous service must be thicker—15 mils or more—than for other environments.

CTFE, with the lowest permeability of the coating resins, is effective as a thin coating (5 to 10 mils). While its chemical resistance is, in many cases, close to that of FEP, it is attacked by primary amines and nonaqueous bases, and is swelled by chlorinated solvents.

Chemical resistance of ECTFE is similar to that of CTFE, but ECTFE is susceptible to oxidative attack at high temperatures. ETFE, which is close to FEP in resistance to most reagents, is also subject to oxidative attack, but resists amines and solvents better than ECTFE and CTFE. The permeability of ETFE is nearly as good as that of ECTFE. Stress-cracking has been observed in both of the ethylene copolymers at a temperature as low as 225 F. PPS behaves much like ECTFE, but is more prone to stress-cracking than swelling when exposed to chlorinated solvents. It has the poorest resistance to acids of all of the high-performance coating resins discussed here.

Table 3 indicates the resistance of high-performance powder coating resins to a variety of chemical compounds and reagents at temperatures to 300 F. These data are guidelines for selecting coatings for chemical applications and should not be construed as a guarantee that a given coating will perform satisfactorily at these temperatures. Values in the table were projected from data in published literature on the base polymers and from tests on samples and coated panels conducted at LNP Corp.

Preparation and Processing

Like all coatings, the high-temperature powders require proper substrate preparation to achieve

Table 4—Application Parameters for High-Temperature Powder Coatings

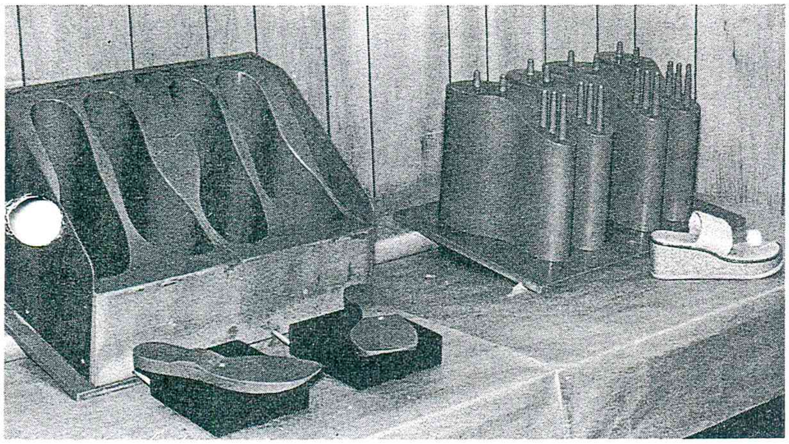
	FEP		ETFE		CTFE		ECTFE		PPS		PPS/PTFE	
Maximum Build (mils)	6	**4**	5	**2**	4	**1**	6	**2**	6	**5**	7	**6**
Maximum Build/Cycle (mils)	12	**6**	10	**6**	5	**4**	14	**8**	16	**14**	16	**14**
Minimum Build (mils)	25	**20**	30	**25**	20	**15**	30	**25**	35	**30**	35	**30**
Preheat Temperature* (F)	625-675	**550-650**	640-660	**640-660**	575-600	**575-600**	550-700	**550-700**	690-750	**690-750**	690-750	**690-750**
Cure Temperature (F)	650	**625-675**	600-650	**600-650**	580-620	**580-620**	500-530	**500-530**	690-750	**690-750**	690-750	**690-750**
Cure Time at Temp (min)												
Base Coat(s)	10-30	**10-30**	2-3	**2-3**	2-3	**2-3**	10-30	**10-30**	30-45	**30-45**	30-45	**30-45**
Final Coat	15-45	**15-45**	4-8	**5-10**	4-6	**5-10**	15-30	**15-30**	60-90	**60-90**	60-90	**60-90**
Degradation Time at Cure Temperature (hr)	10†	**10†**	¼	**¼**	¼	**¼**	1	**1**	4	**4**	4	**4**

Values for electrostatic-spray application are in bold type; values for fluidized-bed application, in light type.
*Preheat is necessary for PPS powders, optional for the fluorocarbons. In practice, however, most parts are preheated to achieve high builds rapidly, except for coatings applied for release properties; these are only about 2 mils thick.
†FEP is very stable in liquid form for long periods, but if cure time is extended, oxidation of the substrate may occur, which weakens the adhesion of the coating.

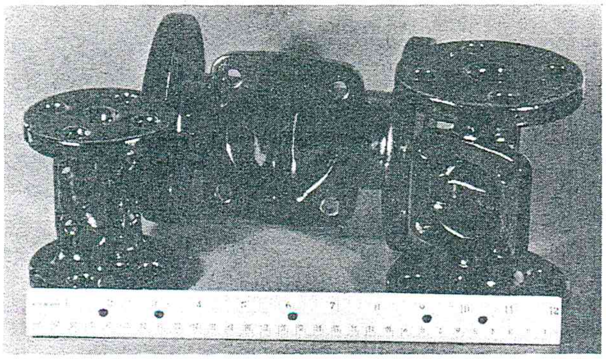
good adhesion, optimum coverage, and maximum properties. Light metals should be sandblasted at 60 to 75 psi with 100 to 120 mesh alumina, flintshot, or quartz. Steel and cast iron require a coarser grit, ranging from 50 to 100 mesh.

Edges of parts should be rounded to minimize stresses in the coating. The high-temperature thermoplastics are crystalline and tend to shrink during cooling; thus the coatings can pull away from stress points created by sharp edges. For parts with edges thicker than 12 ga (0.105 in.), fluidized-bed application is generally preferred over electrostatic spray.

Primers: Although primer materials are available for use with some of the high-temperature thermoplastic powders, they are not used in most custom coating shops for a number of reasons. First is the cost of the additional operation and the need for a different processing line (usually a wet system) than that used for powder application. Second, some primers cannot withstand the preheat and/or cure temperature cycles necessary to apply the powder coatings. Third, a primer (unless electrically and thermally conductive) insulates the metal part, resulting in a thinner coating buildup per pass.



Aluminum molds for urethane shoe soles require a coating that withstands continuous operation at 300 F and that has good release properties. Both are provided in a 15-mil FEP coating applied by Boyd Coatings Research Co., Inc., Gleasondale, Mass., for W. R. Grace Inc.



Diaphragm valves for chemical equipment require not only the maximum in thermal and chemical properties, but resistance to abrasive slurries as well. These valve bodies were fluid-bed coated with 25 mils of PPS by Industrial Coatings Co., of York, Pa., for ITT Grinnell.

Cooling: Some parts can be cooled rapidly to make the coating more amorphous. This improves adhesion and increases impact strength. However, if the part configuration is such that wide variations in temperature occur during cooling, a rapid quench can increase the temperature difference and create stress points in the coating. Problems caused by stresses in the coating may be observed immediately, in the form of edge shrinking, or they may show up later, in the form of stress cracking.

Application: Because it is not as crystalline as the fluorocarbons, PPS shrinks less and is less susceptible to problems caused by part configuration. When PPS is applied by electrostatic spray, the hot part should be covered with a 5 to 10-mil base coating. The material builds quickly, but each subsequent application should be limited to 15 mils. Each coat requires curing for 30 to 45 min; the final coat should be cured for 60 to 90 min. The fluorocarbon powder coatings do not require such long heating cycles, Table 4.

Among the fluorocarbons, ECTFE is the easiest to apply. Like the other fluorocarbon resins, it requires only fusing and leveling during the heating cycle; no chemical change occurs, as it does with PPS.

CTFE cures at a higher temperature than ECTFE and provides the best adhesion of the fluorocarbons. The heating cycle must be carefully controlled, however, because the resin degrades if heated for too long a time or through too many cycles.

ETFE allows the greatest range of builds of any of the high-temperature thermoplastics. Coatings as thin as two mils can be applied to cold parts. Thick coats are obtained by spraying the part hot, returning it to the oven long enough to melt the powder (about 2 min), then respraying. Coatings of 30 mils or more can be applied by this method in less than half an hour. ETFE is also subject to degradation, however, and should not be exposed to a temperature above the melt point for any longer than necessary. A brown color, which develops before any change in physical properties of the polymer, signals the start of overcure.

FEP has the highest melt viscosity of the resins discussed. At the same time, it possesses the greatest melt stability. (It can be maintained as a liquid almost indefinitely with no effect on properties.) Therefore, leveling of a coat, although time consuming, does not affect coating performance. Parts sprayed cold achieve builds of 4 to 6 mils and are cured at 625 F for 45 to 90 min. For parts sprayed hot or dipped in a fluid bed, the optimum cure time is obtained by placing the parts in a 555 F oven, raising the temperature to 645 F over a 20 to 30 min period, then holding for 10 min at 645 F. Final coats should be cured at 555 F for 60 to 90 min. □

Reprinted from MACHINE DESIGN June 12, 1975

Apply a function, not simply a finish, with

Powder Coatings that Fight Heat and Chemicals

BARRY ARKLES
Manager, Technical Development

STEPHEN GERAKARIS
Coatings Specialist
LNP Corp.
Malvern, Pa.

LNP
ENGINEERING PLASTICS
World-Wide in Reinforced Thermoplastics

LNP Corporation
412 King Street
Malvern, Pa. 19355
(215) 644-5200

1831 E. Carnegie
Santa Ana, Calif. 92705
(714) 546-2000

Kalshoven 11
Breda, The Netherlands
01600-73150