



EVERFLON<sup>ACADEMIC</sup>



—— Processing Guide ——

**PTFE**

F100	F500
F1000	F2000

Polytetrafluoroethylene Fine Powder

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# Introduction

Everflon™ PTFE Fine Powder is a milky white polymer which is separated from a dispersion formed by emulsion polymerization. Having a molecular structure of only carbon and fluorine atoms - (CF<sub>2</sub>-CF<sub>2</sub>)<sub>n</sub> - Everflon™ PTFE Fine Powder possesses the lowest coefficient of friction and the most superior heat resistance, chemical resistance, electrical properties and non-sticking property of any plastics. Everflon™ PTFE Fine Powder readily absorbs organic solvents, resulting in the formation of a paste, it can be extruded easily. It is widely used for the manufacture of insulated electric wires, spaghetti tubes, thin rods and unsintered tape.

## Commercially Available Everflon™ PTFE Fine Powders

Properties	PTFE F100	PTFE F500	PTFE F1000	PTFE F2000
Particle diameter (um)	500	500	500	500
Apparent density (g/ml)	0.45	0.45	0.45	0.45
Melting point	328	328	328	328
Specific gravity	2.2	2.2	2.2	2.2
Tensile strength(Mpa)	25	25	25	25
Elongation (%)	350	50	350	350
Reduction ratio	100	600	1500	2000
	Unsintered tape; Sealing tape	Small and large diameter tubes; Shrink tube; Thick electric wire larger than AWG 16 as well as jacketed tubes;	Wrapping tape Tape for wrapping flat cables Tubes Low specific gravity tape Fine electric wire smaller than AWG16	Small diameter tubes Spaghetti tubes Low specific gravity tape Fine electric wire smaller than AWG12

# Major Applications

# Characteristics

# Everflon™ PTFE Fine Powder Applications

## Insulated electric wire

Since Everflon™ PTFE has excellent electrical properties, it is ideal for use as an electric wire insulating material. It also combines the properties of excellent heat resistance and chemical resistance. Typical uses are the following:

- Electric wiring for airplanes, rockets, and missiles;
- Wiring for electric circuit transformers and electric motors; various types of electronic industrial wiring;
- Wiring which is subject to high temperatures, such as in the vicinity of power stations, electric furnaces, or vacuum tubes; and wiring which is effected by strong chemicals used in chemical industries.

## Pipe Tubing

Everflon™ PTFE's superior resistance to heat and chemicals and its nonsticking property are utilized in the following applications:

Pipes for jet engine fuel and rocket fuel;

- Pipes for high-temperature or corrosive fluids in chemical or nuclear plants;
- Pipes for fluids containing food or chemicals;
- Steam hoses; transport pipes for viscous substances;
- Hoses for oil hydraulic control equipment; and insulation for electronic equipment.

## Thin rods

Everflon™ PTFE's excellent electrical properties and resistance to heat and chemicals are utilized in the manufacture of pump and valve parts, terminals, bushings, and outer insulators.

## Unsintered tape

(1) For sealing

Unsintered tape is ideal as a sealing material for threaded joints. Wrapped around the threads, it forms a tight seal with excellent chemical resistance, and heat resistance. Its self-lubricating property also makes removal easy, and it completely prevents the inside of the pipe from being contaminated.

(2) Insulation

When unsintered tape is wrapped around an wire or coil and heated to 330°C (626°F), it shrinks approximately 33% in the direction of calendaring, making it possible to cover the article completely. Layers of tape fuse together forming a completely sealed insulation with no gaps. Unsintered tape is also used for splicing or repairing extrusion-insulated wires made from Everflon™ PTFE Fine Powder.

(3) Film

When unsintered tape is sintered under tension, a film is produced which is used as an insulating material

# Characteristics of Everflon™ PTFE Fine Powders

## Thermal properties

Everflon™ PTFE can be used continuously at temperature up to 260°, and for short periods at even higher temperatures. It also possesses excellent low temperature strength. With these superior thermal properties, products such as electric or electronic machinery components, pipe linings, insulated electric wires, etc., made with Everflon™ PTFE Fine Powder are widely used.

## Chemical properties

Everflon™ PTFE possesses the excellent property of almost absolute resistance to all commonly used chemicals. When used with some special chemicals under extremely severe conditions, such as fused alkali metals, high-temperature, high-pressure fluorine or trichlorofluorine gas, slight changes may occur. With ordinary acids, alkalis, and oxidants at high temperatures Everflon™ PTFE remains completely stable. Even contact with organic compounds does not cause dissolution or swelling. The basic reason for Everflon™ PTFE's extensive use in the chemical industry for pipe linings, wire-braid hoses, gaskets, tubes and bellows is in its chemical inertness.

## Electrical properties

Since the molecular structure of Everflon™ PTFE is non-polar, it is ideal for use as high-frequency insulating material not only because of its applicability over a wide temperature range, but also because of its low, uniform dielectric constant and dissipation factor over a wide frequency range.

Everflon™ PTFE Fine Powder is used for the manufacture of insulation covering for use in aircraft, electrical wiring, small coaxial cables, industrial control cables, spaghetti tubes and wrapping tapes.

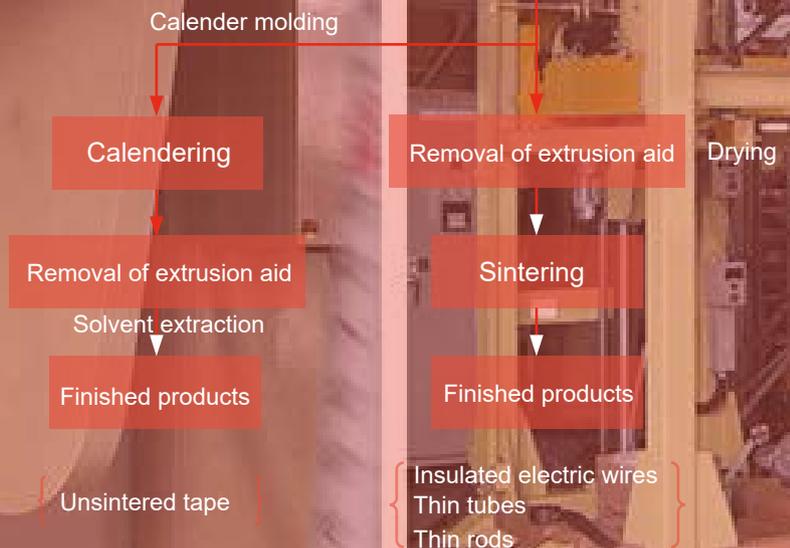
## Low abrasion, non-sticking property

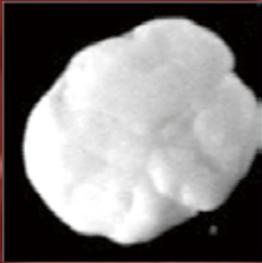
Under ordinary conditions of use, Everflon™ PTFE possesses the lowest coefficient of friction of any solids. Moreover, its remarkable non-sticking property prevents most adhesive materials from adhering to it. Tubes made of Everflon™ PTFE Fine Powder are therefore used as transport tubes for liquid adhesives, cableway pipes, etc., for automobile and other mechanical industries, and other similar applications. In addition, unsintered tape made of Everflon™ PTFE Fine Powder, being extremely soft and malleable, forms tightly to the threads of bolts to provide an excellent sealing effect.

# Fabrication Guide

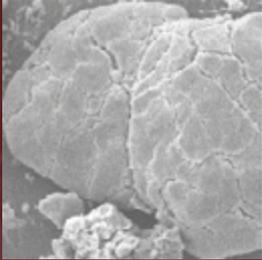
## Paste Extrusion

Compared with ordinary molding powder, Everflon™ PTFE Fine Powder has a smaller molecular weight (3,000,000~5,000,000) and consists of extremely small particles. For this reason, the affinity between Everflon™ PTFE Fine Powder and organic solvents is excellent, and with the addition of ordinary petroleum solvent as an extrusion aid, it can be molded in the form of an organosol. The ordinary molding process for Everflon™ PTFE Fine Powder is shown below

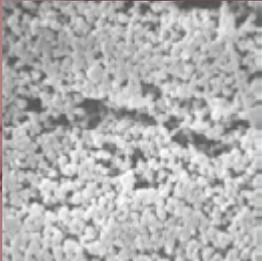




-200um-



-100um-



-1um-

Everflon™ PTFE fine powder consists of “potato-like” secondary particles with a diameter of approx. 500  $\mu\text{m}$  and a specific weight of 500 g/l. The space filling degree is 25 vol %, the PTFE fine powder has an air-filled pore space of 750 ml.

The secondary particle consists of some  $10^{10}$  primary particles that are statistically packed in a spherical agglomeration. The packing density is 55 vol %. A statistical spherical packing of spheres with identical size can, regardless of the sphere diameter, achieve a maximum filling degree of 62 vol %. The spherical primary particles have an extremely tight particle size distribution. The PTFE they contain is in a highly crystalline form.

The potato-like form of the secondary particles ensures the free-flow ability. The grainy, island-like structure of the secondary particle, which can be easily seen, illustrates the statistically packed spherical agglomeration. The particles are “grape-like agglomerates” of  $10^{10}$  primary particles.

# Phenomenology of Paste Extrusion

## Paste Mixing

By adding lubricants, the pore space of the secondary particle is filled. Organic PTFE-wetting fluids are used as lubricants, mostly higher boiling point hydrocarbons (benzenes). In practical use, 20 weight parts of benzene are mixed with 100 weight parts of PTFE. The air in the interior of the secondary particle is displaced by adding lubricants. The potato-like shape of the secondary particle is not modified by this. The paste with the additive still retains its free-flow ability, while the specific weight increases to about 700 g/l. The air-filled pore space between the secondary particles is in the range of 500 ml/l.

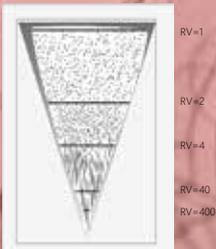
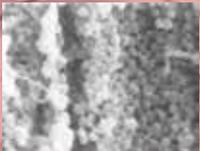
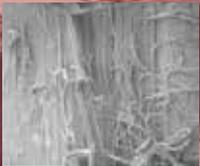
## Preform Fabrication

The air between the secondary particles is removed by compressing them in a cylinder with a pressure of approx. 30 to 50 bar, which increases the density of the lubricant containing material to 1650 g/l. The shape of the secondary particle and the primary particles is thereby preserved. The cylindrical rod resulting from this is called the preform or billet. From the measured density, a filling degree of approx 63 vol %. From the rheological point of view, the fine powder has a paste-like state in the billet. Rheologically, the paste can be defined as a heterogeneous 2-part system consisting of an immobilized fluid and a plastically deformable solid. This system flows when forces exceeding a certain minimum force are applied, and it is irreversibly deformed. The immobilized fluid thereby becomes a lubricant (matrix) and the deformed primary particles are a filling substance.

## Paste Extrusion in Funnel-Flow Design

The billet is transferred to a cylindrical metallic hopper and then pressed through a funnel, also made of metal, at a certain pressure, the so-called paste extrusion pressure. The narrowing of the cross-section in the funnel is characterized by the reduction ratio (RR), which is the ratio of the areas of the funnel inlet and the funnel outlet. Attached to the funnel outlet is a very short piece of pipe, the so-called guide in which the "flowing paste is calmed". In the hopper, the billet material shows plug flow behaviour, as it does not stick to the metallic wall. A real flow process, from the rheological point of view, only starts at the funnel inlet, shown as flow threads in Fig. The flow velocity increases in direct proportion to the narrowing of the RR cross-section. The crowding of the flow threads generates a shear gradient in the direction of the flow. This forces the paste material into an irreversible, plastic deformation. The extruded material gains mechanical stability from the deformation, the so-called "green stability", both in its lubricant-containing, wet state and in the dry state.

The wet extruded material has a density of approx. 1.8 g/cm<sup>3</sup>, while the dried extrudate has a density of 1.6 g/cm<sup>3</sup> and a space filling degree of 70 vol %. This means that the theoretical maximum packing density for spheres of identical size has nearly been reached



## Crack-up of the Secondary Particles

The crack-up of the secondary particle, also called paste fibrillation. It shows the longitudinal section of the funnel cone. The fine powder is mixed with lubricant containing dyed secondary particles before paste preparation. The dye used is benzene insoluble. It is thus possible to see how the deformation of the dyed secondary particles into "longitudinal cylinders" increases with increasing reduction ratio RR.

The crosssection of the cylinder becomes smaller the higher the reduction ratio (RR) gets. The decrease of the cross section is inversely proportional to the RR. It is the result of packet-like regrouping of large primary particle clusters that are transported in the flow direction to the head of the fibrillating secondary particle. The transportation of the cluster is inevitably coupled with primary particles changing place. This induces the pearl-stringlike alignment of the primary particles. The secondary particle is cracked up.

The pearl-string-like alignment of the primary particles should ideally be homogeneous up to ranges of  $<10\ \mu\text{m}$ , larger unaligned "grape-like" clusters should be avoided. Such clusters lead to irregular, unsmooth surfaces of the sintered finished product (orange peel).

## Reversible Deformation of Primary Particles

Paste extrusion is accompanied by an enlargement of the extrudate, i.e. the extrudate has a larger diameter than the guide. This can be proof that an elastic deformation of the primary particles has taken place, as they are the only ones able to store elastic energy. The shear gradient in the flow direction deforms the spherical primary particles into ellipsoids. The primary particles are kneaded. After leaving the guide, the elastic tensions relax and the primary particle returns to its original spherical shape. This means that the deformation is reversible. All that remains is a more compact structure.



# Fundamentals of Everflon™

## PTFE Fine Powder Processing

### Packaging and Storage

Everflon™ PTFE Fine Powders are produced in electronically-controlled processes (process control system) and filled under clean-room conditions (clean room class 100). They are packed in tightly-closable plastic drums with a filling quantity of 20 kg.

The PTFE production facility, as well as the quality of the drum container with lid and seal, eliminates the need for dry bags, which also avoids possible contamination due to damage to the dry bag. The material is filled and stored at temperatures below 19 °C. In the hotter months of the year, the product is usually shipped in refrigerated trucks in order to avoid clumping due to transportation and/or heat and to maintain the good free-flowability of the fine powder.

In order to preserve these powder properties, it is recommended that customers store the products in refrigerated rooms; where possible at temperatures below 19 °C, the point at which crystallite is transformed.

A room temperature of 15 °C is recommended. Should the fine powder be found to be clumpy or contain agglomerates, despite these precautionary measures, then the latter can be sieved out (caution: do not apply pressure to the particles, do not contaminate the powder). The separated agglomerates should be refrigerated for 2 to 3 days at a temperature of between 5 and 10 °C, and then shaken in order to break apart the agglomerates.

They should then be screened at temperatures below 19 °C by which the agglomerates should fall apart into free-flowing powder. It takes more than 24 hours until the fine powder material is ready for further processing and approx. 3 days to cool the material down to 5 °C. A more practical solution would be a cold room temperature of 15 °C where the cooling of the PTFE down to 15 °C extends over several days.

## Preparation of the Extrusion Mixture

In order to avoid flaws in the finished product, care must be taken during processing of the fine powder to avoid all excess mechanical stress of the powder, as it is highly shear-sensitive. It is recommended to shake the powder carefully or scoop it out in order to avoid crushing the particles.

## Powder Screening

Before pouring it into the mixing container, the fine powder should be screened in order to break apart any agglomerates and to loosen it. The mesh size of the screen should be 3 to 4 mm. The use of riddle sifters is also possible, which allows harder agglomerates to be broken apart. Larger clumps that do not fall apart should be removed from the screen and collected in a separate container. The separated agglomerate particles can be reprocessed through cooling and renewed screening. Utmost cleanliness is important during the open screening process. Moisture absorption due to air condensation must be avoided by maintaining the drum at ambient temperature and reclosing it immediately after powder removal. PTFE is a good electrical insulator, so when dosing PTFE it is necessary to avoid high pouring speeds, as the material could otherwise become charged with static electricity and then explode in combination with the lubricant.

## Mixing with Lubricants

Aliphatic hydrocarbons with different boiling ranges have proven useful as lubricants for paste extrusion.

The choice of the lubricant is dependent on the type of extrusion material. Lubricants with a higher boiling range are usually used for thin-wall applications requiring a calendaring process, such as films. Lubricants with a lower boiling range are used for thick-walled extrusion materials such as liners.

The selected lubricant should be well absorbed by the fine powder and equally well removed after the extrusion. It should also not cause discolorations during sintering. Depending on the application and the lubricant type, the lubricant content amounts to 17 to 25 parts by weight related to 100 parts by weight of Everflon™ PTFE Fine Powder. The quantity of the lubricant is stated in parts by weight for simplicity's sake. However, it would be more correct to say that the optimum volume of lubricant is added to the PTFE fine powder, as the void volumes between the primary particles that has to be filled. Here, the density of the lubricant, that may vary by around 10 - 15 %, plays a role. The lubricant is added to the powder in the centre of the mixing container, not at its edge.

The mixing procedure should be carried out at a temperature below 19 °C as the fine powder has a better free-flow behaviour at these temperatures. Depending on the type of mixer (dolly or tumbling mixer), the mixing time is between 20 and 30 minutes with a speed set at 20 to 30 revolutions per minute. The powder mix should flow and not splash in the mixing container. The lubricant is absorbed uniformly by the powder. The mixing containers must be tightly sealed in order to avoid evaporation losses. The mixing container should be filled to a maximum of 2/3 of its volume in order to attain a good mix.

Earthing is important when mixing the fine powder with the flammable lubricant due to the ignition risk of the lubricant vapours, e.g. ignition caused by electrostatic charge. The benzene concentration in the working rooms must be monitored with the help of suitable room air monitoring devices. Good ventilation should also be provided.

## Pigmentation

The following procedures are recommended for pigmenting or colouring the powder paste: When using liquid colour suspensions, add these to the lubricant before mixing with the powder paste. If the pigment is to be mixed with the powder paste in a dry state (e.g. for antistatic applications, carbon black dyeing), the pigment is screened directly onto the powder and the mix is then homogenized in dry state through rolling.

## Maturing of the Extrusion Mix

A homogeneous distribution of the lubricant in the PTFE can be obtained by letting the mix “mature”. This ripening process should take overnight or at best over 24 hours in tightly sealed containers. Longer times are not necessary.

## Preform Compression

In this processing step, the mix of Everflon™ PTFE Fine Powder and lubricant is fed into a preform press where it is compacted into a cylindrical preform.

The aim of the compression is to eliminate the air contained in the mix of powder paste and lubricant and to bring the mix into a form that can be fed into the extrusion cylinder without any problems. The cylinder of the preform press should be three times the length of the preform, as the powder is compressed to 1/3 of its volume.

The mix of powder and lubricant should be compacted slowly so as to allow the air to completely escape from the mix in the preform cylinder. This process can be supported by a vacuum placed at the ventilation bores. Pre-pressing takes several minutes at a pressure of approx. 30 - 50 bar. The quality of the finished products is, among other things, dependent on a preform without cracks. The compression pressure is therefore only slowly decreased and care must be taken when removing the preform from the preform cylinder. The compacted part must then be immediately processed to reduce evaporation of the lubricant from the surfaces to a minimum.

Inhomogeneous distribution of the lubricant results in quality and dimensional variations of the finished product. The preform is fed into the paste extruder – the cylinder of which should have a diameter that is 1 mm larger than the outer diameter of the preform.

# Trouble Shooting Guide

Problem	Possible cause	Suggested remedy
Contamination of the semi-finished product	Contaminated lubricant has been added	<ul style="list-style-type: none"><li>• Filter lubricant</li><li>• Change the lubricant batch</li></ul>
	During opening of the powder drum	<ul style="list-style-type: none"><li>• Before opening, remove dirt particles from the outside of the drum to avoid contamination</li><li>• Earth the drum to avoid electrostatic charges</li><li>• Clean the preparation room</li></ul>
	Prior extrusion contained fillers	<ul style="list-style-type: none"><li>• Clean extruder</li></ul>
Brown coloration of the semi-finished product	Lubricant has not been fully removed	<ul style="list-style-type: none"><li>• Increase drying period</li><li>• Increase drying temperature</li><li>• Use lubricant with lower boiling point</li><li>• Improve suction in the oven</li><li>• Repeat sintering, brown colour will disappear in most cases</li></ul>
Extrudate is brittle	Extrusion pressure is too low, green strength is too low	<ul style="list-style-type: none"><li>• Increase reduction ratio</li><li>• Reduce lubricant quantity</li><li>• Use material with higher extrusion pressure</li><li>• Increase extrusion speed</li></ul>
Semi-finished product is torn in extrusion direction	Mechanical damage in green state	<ul style="list-style-type: none"><li>• Treat extrudate more carefully</li><li>• Use lubricant with higher boiling point</li><li>• Check die for mechanical damage</li></ul>
Sintered semi-finished product has low tear resistance but high density and elongation at break	Sintering of semi-finished product too long or too hot	<ul style="list-style-type: none"><li>• Check temperature profile of the sintering oven</li><li>• Choose lower sintering temperature (360 to 380 °C)</li><li>• Check for oven malfunctions</li></ul>
Liner is torn lengthwise and crosswise to extrusion direction	Inner supporting pipe was too big	<ul style="list-style-type: none"><li>• Use smaller inner supporting pipe</li></ul>
	Irregular cooling after sintering	<ul style="list-style-type: none"><li>• Ensure uniform cold air distribution</li><li>• Check for malfunctions of oven or cooling unit</li></ul>
	Inner tensions or irregular shrinkage because cooling was too fast	<ul style="list-style-type: none"><li>• Slow down cooling process</li><li>• Check for malfunctions of oven or cooling unit</li></ul>
	Semi-finished product stuck to contact surface during sintering	<ul style="list-style-type: none"><li>• Check contact surface for roughness or flaws</li></ul>

Problem	Possible cause	Suggested remedy
Semi-finished product burst open	Drying temperature is too high	<ul style="list-style-type: none"> <li>Reduce drying temperature to the range between boiling point of the lubricant and sintering temperature</li> <li>Check for oven malfunctions</li> </ul>
	Moisture	<ul style="list-style-type: none"> <li>Dry lubricant</li> <li>Water condensation when opening the powder drum,bring drum to room temperature</li> </ul>
	Trapped air during preform fabrication	<ul style="list-style-type: none"> <li>Check machine parameters (pressure, time, closing speed)</li> <li>Drill ventilation bores</li> </ul>
Partial tapering of the tube diameter or wavy extrudate, "snake-effect"	Too much lubricant	<ul style="list-style-type: none"> <li>Reduce lubricant content</li> </ul>
White dots in the semi-finished product	Contamination or PTFE residues from prior extrusions	<ul style="list-style-type: none"> <li>Clean extruder</li> </ul>
	Squeezed powder paste	<ul style="list-style-type: none"> <li>Treat powder more carefully</li> <li>Check lubricant level</li> <li>Screen agglomerates</li> </ul>
Partial occurrence of streaks	Excess lubricant	<ul style="list-style-type: none"> <li>Reduce lubricant level</li> </ul>
	Squeezed powder paste	<ul style="list-style-type: none"> <li>Treat powder more carefully</li> <li>Screen agglomerates</li> </ul>
	Irregular lubricant distribution	<ul style="list-style-type: none"> <li>Extend mixing time</li> <li>Let lubricant-powder mix rest overnight at 30 °C</li> </ul>
Scaly surface of the semi-finished product(orange peel)	Shearing in extrusion die too low	<ul style="list-style-type: none"> <li>Increase reduction ratio</li> <li>Increase extrusion speed</li> </ul>
	Rough tool finish	<ul style="list-style-type: none"> <li>Polish</li> <li>If lateral polish is applied, polish longitudinal</li> </ul>
	Lack of lubricant	<ul style="list-style-type: none"> <li>Increase lubricant level</li> </ul>
Irregular surface	Lack of lubricant	<ul style="list-style-type: none"> <li>Increase lubricant level</li> </ul>
	Irregular lubricant distribution	<ul style="list-style-type: none"> <li>Let lubricant/powder mix rest overnight at 30 °C</li> </ul>
	Inconsistent drying and sintering conditions	<ul style="list-style-type: none"> <li>Check for oven malfunctions</li> </ul>
	Filler agglomerates in dry-mixed fine powder compound	<ul style="list-style-type: none"> <li>Reduce filler-particle size</li> <li>Increase dimensions of semi-finished product</li> <li>Grind, crush or screen filler</li> <li>Filler or filler additives not temperature-resistant enough</li> </ul>



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