Analysis of PTFE: Why does it seal well?

Relevant for: thin films, elastomers, gas physisorption, atomic force microscopy, surface area, nanostructure analysis, surface roughness, fibers, membranes

PTFE tape is commonly used to seal gaps, cracks and gas leaks. By means of gas physisorption and atomic force microscope (AFM), we shed light on why PTFE powder and tape seal so well. This approach can also be used to analyze other flexible materials, thin films/coatings, and novel elastomers.

1 Introduction

Figure 1: PTFE powder. Notice the inherent clumping (due to its fluorine molecule interactions), even though it is hydrophobic in nature.

Polytetrafluoroethylene (PTFE) is a synthetic polymer composed of tetrafluoroethylene chains, discovered in 1938 by Roy Plunkett at DuPont.[1] PTFE is hydrophobic, has the third lowest co-efficient of friction among all materials (0.05-0.1) and low thermal conductivity, but high melting point (326 °C) and density (2.2 g/cm^3).[2] Common industrial uses of PTFE include use in anti-friction materials (lubricants, grease, etc.), creating hydrophobic fabrics, use in high temperature membrane filters, dental filings, among others.

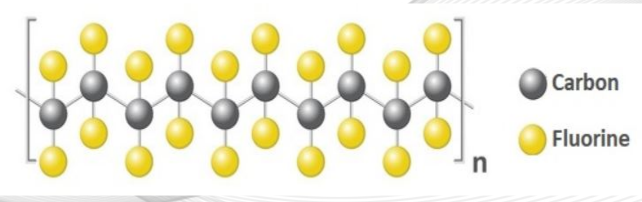

Figure 2: Structure of PTFE showing cross-linked C-F molecules.

This approach makes use of multiple measurement techniques like gas physisorption (surface area information) and atomic force microscopy (AFM, surface morphology) to throw light on why PTFE is able to seal gaps in materials very well. The purpose of this note is also to show how a material (like PTFE) can be analyzed at the textural level to give a complete explanation of its physical, real world performance attributes. When developing novel materials, we typically need information on: a) how the material will behave at the sub-nm level (PTFE powder) by measuring surface area and b) what is the nature of the material when extruded into thin flexible sheets, PTFE sealing tape just being an example.

2 Experimental

Two different techniques were used in the characterization of PTFE – gas physisorption (autosorb iQ series) and atomic force microscopy (Tosca 400 AFM) to measure the surface area and surface topography respectively. PTFE powder was used for measuring the BET surface area with nitrogen gas, while a white PTFE sealing tape was used for surface texture analysis. The results of these measurements are summarized below in Table 1.

Results	Value	Technique used
BET surface area (m^2/g)	2.59	Gas (N_2) physisorption
RMS roughness (nm)	170	AFM
Average fiber width (nm)	330	AFM

Table 1: Physical properties of PTFE as measured by two different characterization techniques.

For gas physisorption measurements nitrogen gas at 77 K was used while helium gas was used to measure sample cell void volume. ~ 2 g of PTFE powder was used to fill a 9 mm large bulb sample cell of the autosorb iQ system. Samples were degassed at 343 K for 3 hours prior to the measurement. BET surface area was calculated in the p/p_0 range from 0.1-0.25.

A 1 cm x 1 cm piece of PTFE tape was cut and used for AFM measurements. The Tosca AFM was operated in tapping mode for capturing height and phase contrast of features. The tapping mode cantilevers used were Arrow-NCR10 silicon sensors from Anton Paar, with a nominal resonance frequency of 285 kHz and a force constant of 42 N/m. Cantilever dimensions were 160 µm in length and 45 µm in width. The image scan rate was ~0.5 Hz, while scan resolution was set to 400. All measurements were done at ambient, room temperature conditions.

3 Results and Discussion

3.1 Gas physisorption (autosorb iQ)

This technique is used to measure surface area of materials. Typically nitrogen gas is used as a “probe” molecule to adsorb onto the external and internal surfaces of the materials at a constant temperature (77 K for nitrogen). The BET surface area is then calculated from the monolayer adsorption region of the isotherm. A complete explanation of BET theory can be found elsewhere.[3] Materials which have a good sealing property, typically have low (< 10 m^2/g) surface area values. BET surface area as shown in Figure 3 was measured on two PTFE powder samples and the average value was 2.59 m^2/g. This low value is expected for generally non-porous materials like PTFE.

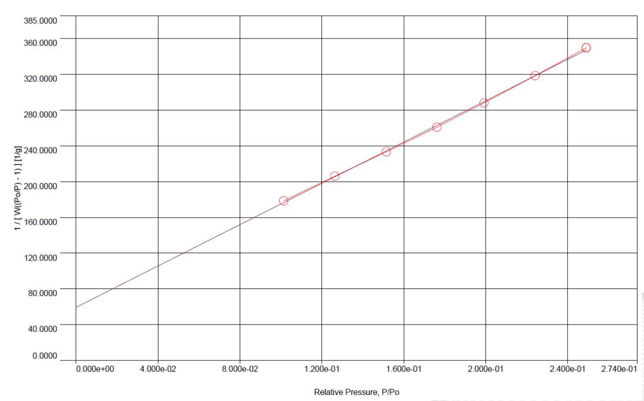

Figure 3: BET surface area of PTFE powder : 2.59 m^2/g.

3.2 Atomic force microscopy of PTFE tape

AFM allows characterization of surface morphology, roughness, and check for presence of impurities or inhomogeneity’s (if any) at the nm-scale. The 3-D surface topography of PTFE tape surface is shown in Figure 4. The RMS roughness of tape was measured to be 170 nm. The surface topography shows the fibrous structure of PTFE tape. Surface morphology is important for knowing properties of the tape like feel, smoothness, absence/presence of fibers and/or contaminants.

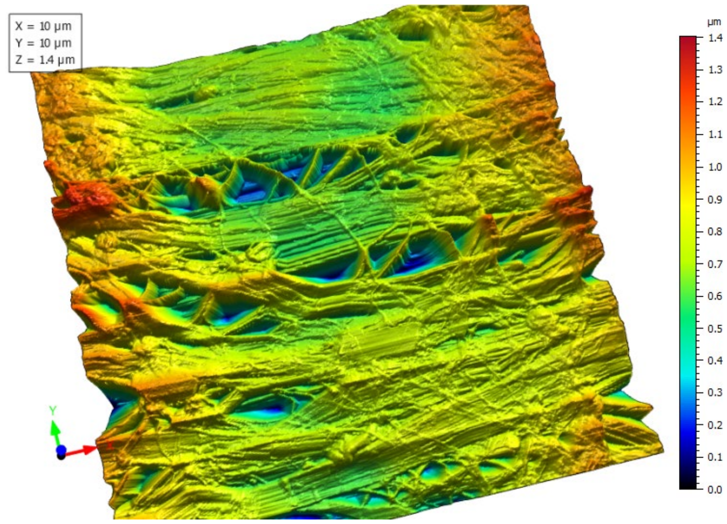

Figure 4: 10x10 µm 3-D topography (forward trace) AFM image of the PTFE tape surface showing fibrous composition of the tape.

The average width and height of these fibers was measured from the AFM height image to be 330 nm and 480 nm respectively. These values were measured from the 2-D surface profiles perpendicular to the fiber.

These two characterization techniques together show why PTFE is such a good sealing material. The low surface area (low porosity) provides a non-porous barrier to gas and liquid as per the desired application. This property combined with the fibrous nature of the tape (as shown in Figure 4) allow the tape to stretch and conform into tight gaps. The high melting point and low thermal conductivity of PTFE also makes it suitable for high temperature sealing applications.

4 Summary

We have shown how two different material characterization techniques like gas physisorption and AFM can work together to provide a complete picture of the PTFE tape surface. This combined approach can also be extended to other similar materials for correlating the physical properties to application.

5 References

1. www.sciencehistory.org, retrieved 12 Dec. 2020.
2. PTFE MSDS, The Chemours Company.
3. www.wiki.anton-paar.com/en/bet-theory

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