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Original Article

Examination of Polyvinylidene Fluoride (PVDF) and Fluorinated Ethylene Propylene (FEP) as Binder in Positive Electrode of Lithium-ion Battery

Fidelis Nwabunike Okonkwo

[1]*Mechanical Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka, Nigeria*.

Corresponding Author : fidelisokonkwo78@gmail.com

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Abstract - *The binder composition of the battery electrode can be linked to its performance in different ways as a result of a slight impact on the external properties. The binding material in lithium-ion cathode electrodes largely adds to the operation yardstick, including the cycling balance, capacity and efficiency rate, although electrochemically passive. In this study, a comparative assessment of Polyvinylidene fluoride (PVDF) and Fluorinated Ethylene Propylene (FEP) electrodes containing 5 wt% of binder in the positive electrode of a lithium-ion battery is presented. By comparing the electrochemical and physical properties of PVDF and FEP electrode binder with CES, EduPack Software generated property charts. The generated results present PVDF with properties like hardness, 15HV, tensile strength, 50MPa, compressive strength, 110MPa, density, 1780kg/m^3 and price, NGN2,650 in comparison with FEP that bears hardness, 5HV, tensile strength, 21MPa, compressive strength, 15MPa, density, 2170kg/m^3 and price, NGN4,900. The results serve a multifaceted purpose beyond a mere comparison but offer a deeper understanding of the consequences associated with any chosen material.*

Keywords - *Lithium-ion battery, PVDF, FEP, Binder, CES EduPack.*

1. Introduction

Standard lithium-ion batteries have transformed into traditional energy storage devices which found their application in numerous moveable consumer electronics gadgets [1,2,3,4,5]. Because of these advantages, which include minimal self-discharge, high specific energy, enhanced cycle life, lightweight, high working voltage, and portability, their utility extends to various domains. Graphite anode and phosphate or transition metal oxide cathode electrodes are the standard components of Li-ion cells [6,7,8]. The electrodes, separators, and electrolytes are some of the essential parts that determine the LIBs' dependability and performance. The selection of binder materials for the electrodes is one of the most important factors that affect the overall longevity and performance of Lithium-ion batteries. Typically, the electrode is composed of conductive additive compounds, a binder, and an active substance. In high-capacity batteries, the proportion weight of inactive electrode components like the binder and conductive additive is reduced [9].

According to several studies, binder is a crucial component of cell electrodes because it acts as an active diffusion factor that firmly binds the various electrode types to the current collector [10,11,12,13, 14]. Due to its excellent electrochemical and thermal properties as well as its remarkable cohesion characteristics between the current collectors and electrode films, polyvinylidene fluoride, or PVDF, is the binder that is most frequently used for both the positive and negative electrode of lithium-ion cells [15,16,17,18, 19]. Due to its exceptional mechanical stiffness, thermal stability, and piezoelectric properties, PVDF emerges from the fluoropolymer backdrop, as demonstrated in Figure 1a. It is easily produced and has characteristics that make it resistant to chemicals in a variety of materials [20]. Although extremely elastic, fluorinated by-products with similar properties can also be employed as binders, polyvinylidene fluoride is primarily used as electrode binders [21, 22, 23, 24, 25]. The use of these secondary binders is controversial due to their implications on the environment and the economy [26,27,28,29,30,31]. Inconsistency compromises the integrity and unity of the molecule and can cause mechanical degradation of the electrode [21, 32, 33]. Liu et al. observed that increasing the battery's stack pressure can alleviate the electrode conductivity loss caused by binder bulging [34, 35, 36]. However, because of their chemical dormancy during redox processes, PVDF binders have certain advantages in the range of Li-ion setups [37, 38]. A greater performance rate and larger capacity were obtained from research into the improvement of the conductive additive leakage system by optimizing the carbon black-binder ratio [34, 39, 40]. Hexafluoropropylene and tetrafluoroethylene copolymerize to form Fluorinated Ethylene Propylene (FEP), a resin covering with a very low coefficient of friction and high-temperature resistance [41]. It is resilient to UV light and has remarkable electrical properties. Figure 1b illustrates how fully Fluorinated Ethylene Propylene (FEP) copolymers exhibit strong chemical and thermal stability. Conventional methods are unable to measure the molecular weight of FEP, which is related to polytetrafluoroethylene (PTFE). Melt flow rate (MFR) is used to characterize the molecular weight of FEP. Its properties are the same as those of polytetrafluoroethylene (PTFE) and perfluoroalkoxy (PFA). FEP exhibits a dielectric transition at 150 °C that is independent of crystallinity [42, 43].

To get around some of the drawbacks of using traditional binders, researchers have experimented with customized binders. Achieving high energy density lithium batteries and better mechanical qualities is one of the main design difficulties. Polymer binders that have been historically utilized in the cathode, anode, and separator materials were examined by Siyeon et al. Taking into account the present emphasis on battery performance development and environmental responsibility, they provided a variety of binder alternatives that can be in line with the changing landscape of environmentally friendly and sustainable battery production. Additionally, by maintaining the structural integrity of electrodes, binders are essential to lithium-based rechargeable batteries. Although binders make up a minor portion of the electrode's overall composition, their effect on battery performance is substantial. To attain dependable and uniform cycling performance in the electrode structure, binders and additives need to be suitably adjusted and customized. Due to its electrochemical stability and ability to flexibly withstand mechanical compression during the charging and discharging processes, polyvinylidene fluoride binder is a widely used option [44].

Fluorinated thermoplastic binders with various physicochemical characteristics and particle sizes were compared by Gerrit et al. In a two-stage method where the first step serves the production of a carbon black-binder-matrix and the second step serves the gentle homogenization with the active ingredient, powder mixing experiments were carried out at various times. Larger binders relative to the active material in the PVDF under investigation are unsuitable for the dry mixing method, and the retention of big binders in the mixture leads to an unstable electrode coating. Stable electrodes might be produced by processing the binders and tetrafluoroethylene-hexafluoropropylene-vinylidene with noticeably smaller particles. Although the binder is comparatively evenly dispersed throughout the electrode, it is nevertheless richer in some areas. As a result, compared to electrodes that have been wet-treated, there is less adhesion to the current collector. The durability and performance in the future are influenced by the binder selection and how it is handled throughout the mixing process [45].

The majority of current lithium-ion battery research investigations have concentrated on various active electrode materials and appropriate electrolytes for applications requiring high cutoff voltages. Although not much has been accomplished in terms of characterization of lithium-ion battery binder, binder maintains the cycle performance and structural integrity of electrodes.

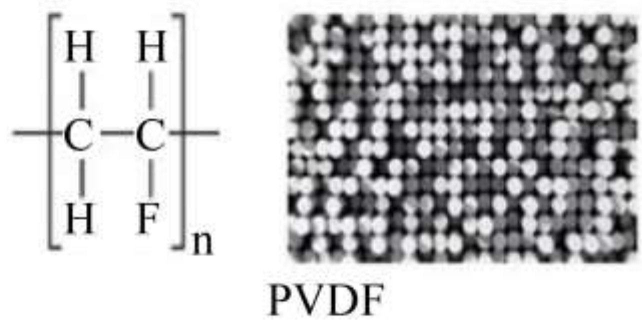

Fig. 1(a). Schematic molecular structure of PVDF [46]

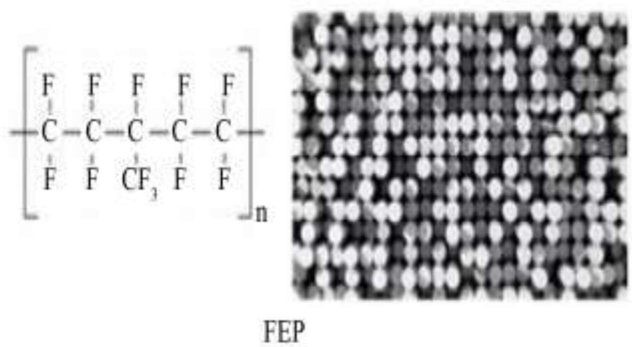

Fig. 1(b). Schematic molecular structure of FEP [47]

The production method, characteristics, shape, and scale of structural members, as well as the way structural components operate, must all be taken into consideration when choosing a material. The materials are depicted in Figure 2, where height and breadth are determined by the boundaries of the characteristics' values. In this study, the positive electrode of a Li-ion battery underwent a comparative material property assessment using CES EduPack Software between polyvinylidene fluoride and fluorinated ethylene propylene binder. The software produced material property charts and examined the hardness, tensile strength, compressive strength, density, and pricing in addition to producing other qualities. The characterization approach under investigation has the ability to overcome existing constraints. The materials and methods, results and discussion, introduction, and conclusion are the four sections that make up this study.

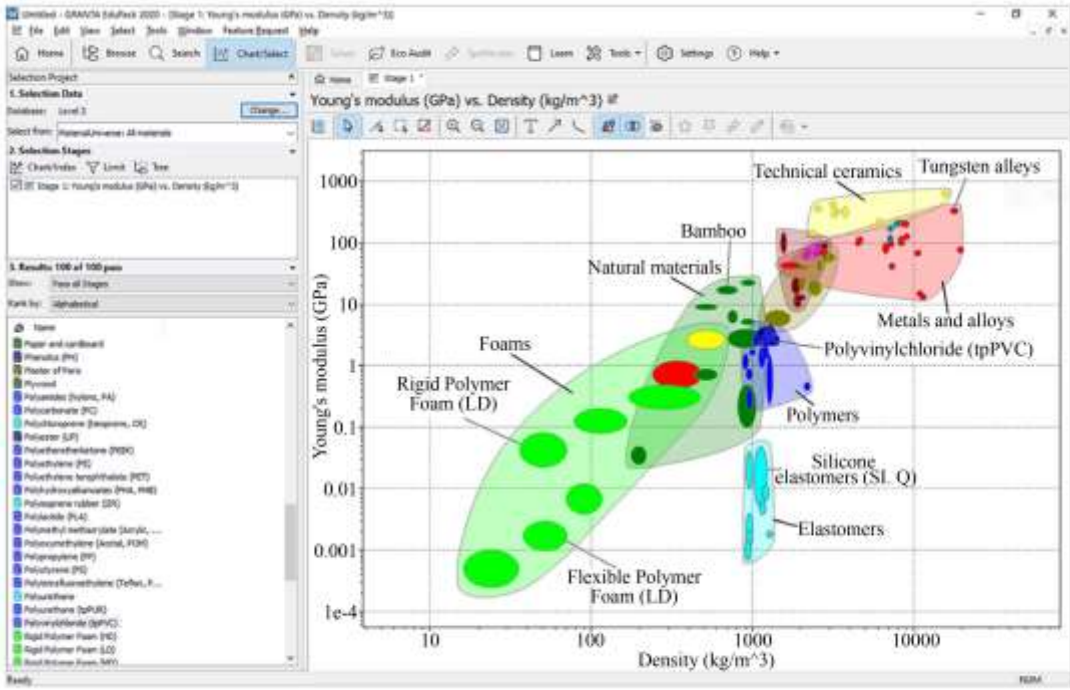

Fig. 2 CES EduPack materials property chart user interface [48]

2. Materials and Methods

For this investigation, a layered lithium nickel manganese cobalt oxide positive electrode of a Li-ion battery, BZ605080, with 5 weight percent of binder, was used, as Tables 1 and 2 demonstrate. Plotting the two binders; PVDF and FEP—into material property charts, sometimes referred to as bubble charts or Ashby charts, allowed for their exhibition and comparison. The advanced setting of the CES EduPack software provides a more thorough description of the chosen material's properties. The thermal, impact, electrical, general, optical, tensile, hardness, mechanical, and processability properties of polyvinylidene fluoride and fluorinated ethylene propylene are taken into consideration for the purposes of this study. The software generates bubble charts of the two binder materials and provides easy material property analysis by considering the numerical values of each property as created by the charts. The appendix contains the specifics of the material property analysis.

Table 1. The composition and characteristics of the positive electrode

No	Item	Parameter	Note
1	Active-Material $Li(Ni_{0.5}Co_{0.2}Mn_{0.3})O_2$. NMC	92 %	Percentage weight of active material (NMC)
2	Binder (PVDF+FEP)	5 %	Percentage weight of binder
3	Conductive additive	3 %	Percentage weight of conductive
4	Current collector	15 μm	Thickness of Aluminium foil
5	Electrode porosity	33.2 %	Positive electrode
6	Coating	40.5 μm	Coating thickness
7.	Loading (active)	10.4 mg/cm^2	
8.	Loading (coating)	11.1 mg/cm^2	

Table 2. The physical state of the lithium-ion battery

No	Item	Parameter	Note
1	Cell Thickness	6.0 mm	
2	Cell Width	50 mm	
3	Cell Height	80 mm	
4	Cell Weight	57 g	
5	Appearance	Pouch	

3. Results and Discussion

The tensile strength and hardness curve for the binders are displayed in Figure 3. According to the chart, fluorinated ethylene propylene (FEP) has a lower tensile strength of 21 MPa and a lower hardness of 5 HV than polyvinylidene fluoride (PVDF), which has a greater hardness of 15 HV. The binders' hardness and compressive strength curve are displayed in Figure 4. According to the chart, fluorinated ethylene propylene (FEP) has a compressive strength of approximately 15 MPa and a lower hardness of approximately 5 HV than polyvinylidene fluoride (PVDF), which has a greater hardness of approximately 15 HV. The density and pricing chart for the binders is displayed in Figure 5. According to the figure, fluorinated ethylene propylene (FEP) has a higher density of 2170 kg/m3 and costs NGN4900, whereas polyvinylidene fluoride (PVDF) has a lower density of 1780 kg/m3 and costs NGN2650. According to the collected results, fluorinated ethylene propylene (FEP) has a good density and flexible mechanical strength. In contrast, polyvinylidene fluoride (PVDF) is the best material in terms of hardness, tensile strength, compressive strength, and pricing. The study thus emphasizes the necessity of carrying out further research on a variety of binder alternatives in order to conform to the changing sustainability and durability standards.

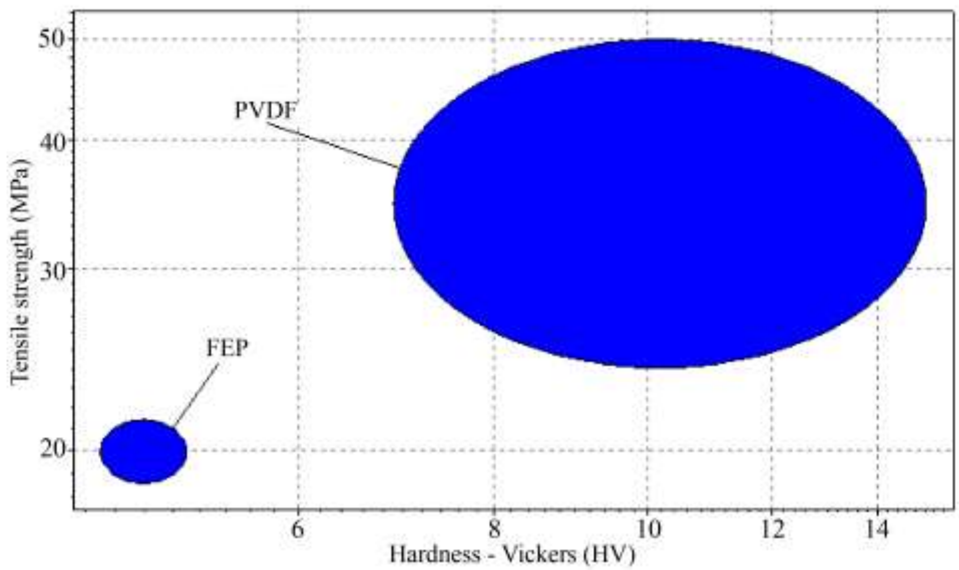

Fig. 3 Chart of hardness against tensile strength for PVDF and FEP

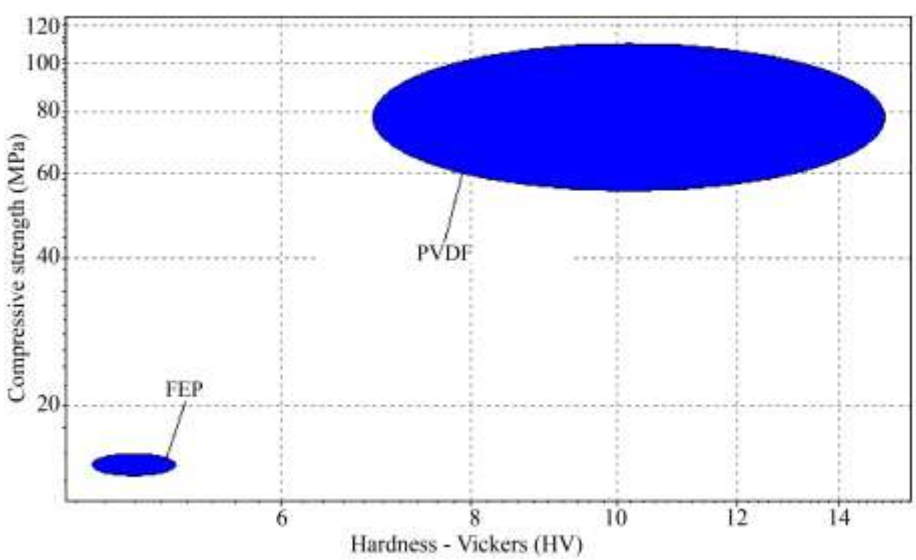

Fig. 4 Chart of hardness against compressive strength for PVDF and FEP

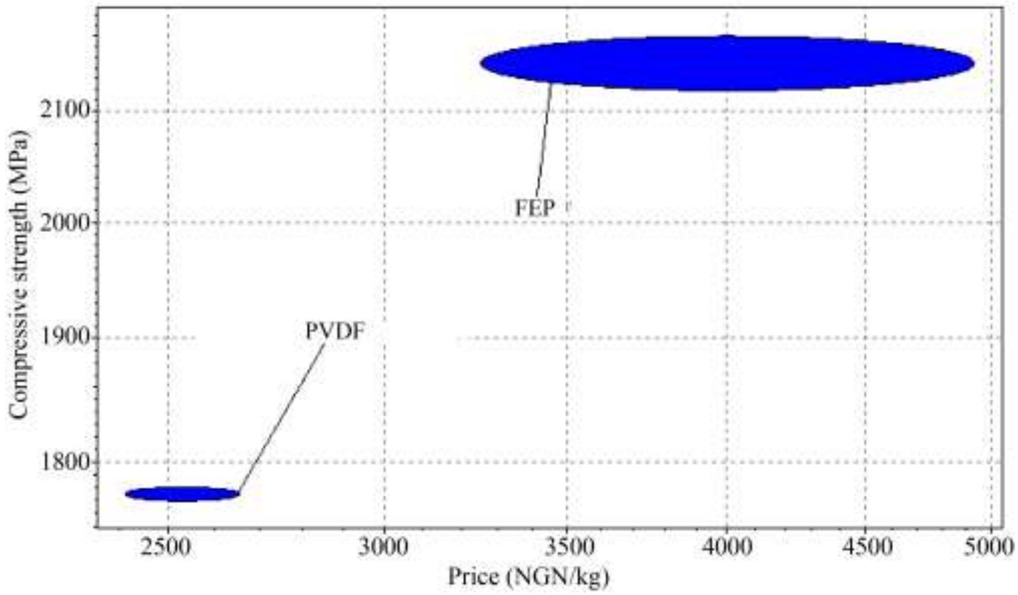

Fig. 5 Chart of density against price for PVDF and FEP

4. Conclusion

Using the CES EduPack Software, this study compared the characteristics of polyvinylidene fluoride (PVDF) and fluorinated ethylene propylene (FEP) as binders in the positive electrode of a Li-ion battery. Examining material attributes provides a more in-depth comprehension of the effects of material decisions. Researchers and engineers can predict how a material will behave in real-world circumstances by analyzing qualities like mechanical, thermal, electrical, and more. This allows them to make well-informed decisions that are in line with production needs. It is impossible to overestimate the importance of polymer binders in lithium-ion battery electrodes. In order to better understand the multi-variable binder systems, dynamic tools like advanced characterization and modeling should be used; this will also improve the polymer binders' mechanical, surface, and electrochemical properties. In addition, other benefits, including ecological tolerance, self-sustenance qualities, mechanical flexibility and flaccidity, can be incorporated into next-generation electrode binder approaches to further increase battery efficiency. But many batteries are turned off when they simply can no longer be used for a certain purpose, such as powering a car, even while they still have energy for other uses, most notably renewable energy applications. It is imperative that engineers and scientists exercise creativity in determining the most effective methods for recovering, regenerating, and redesigning lithium-ion battery materials, particularly in the design phase. Batteries and other green energy sources are crucial for a future with moderate carbon emissions. It is necessary to create relevant policies to guarantee that they are safe, hygienic, and sustainable.

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Appendix

Polyvinylidene Fluoride (PVDF)
General Properties
Designation
Polyvinylidene Fluoride (Homopolymer, Molding and Extrusion)

Density	1.77e3	-	1.78e3	kg/m^3
Price	2.41e3	-	2.65e3	NGN/kg

Trade names
Dyflor; Hylar; Hyflon; Kynar; Solef; Tecaflon
Composition overview
Composition (summary)
Homopolymer of vinylidene fluoride, $(CH_2CF_2)n$

Base	Polymer	
Polymer class	Thermoplastic : semi-crystalline	
Polymer type	PVDF	
Polymer type full name	Polyvinylidene difluoride	
% filler (by weight)	0	%

Filler type	Unfilled			
Composition detail				
Polymer	100			%
Mechanical properties				
Young's modulus	2	-	2.5	GPa
Compressive modulus	2.09	-	2.89	GPa
Flexural modulus	2	-	2.5	GPa
Shear modulus	* 0.194	-	0.486	GPa
Bulk modulus	* 1.79	-	1.88	GPa
Poisson's ratio	0.413	-	0.432	
Shape factor	4			
Yield strength (elastic limit)	23	-	50	MPa
Tensile strength	24.1	-	50	MPa
Compressive strength	* 55.2	-	110	MPa
Flexural strength (modulus of rupture)	66.9	-	94.1	MPa
Elongation	12	-	600	% strain
Hardness - Vickers	* 6.9	-	15	HV
Hardness - Rockwell M	* 48	-	52	
Hardness - Rockwell R	79	-	85	
Fatigue strength at 10^7 cycles	* 9.64	-	20	MPa
Fracture toughness	* 2.39	-	2.86	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.029	-	0.0725	
Impact properties				
Impact strength, notched 23 °C	7.39	-	22	kJ/m^2
Impact strength, notched -30 °C	3.21	-	5.39	kJ/m^2
Impact strength, unnotched 23 °C	133	-	200	kJ/m^2
Impact strength, unnotched -30 °C	122	-	200	kJ/m^2
Thermal properties				
Melting point	141	-	178	°C
Glass temperature	-40	-	-27	°C
Heat deflection temperature 0.45MPa	* 108	-	146	°C
Heat deflection temperature 1.8MPa	84	-	118	°C
Maximum service temperature	157	-	175	°C
Minimum service temperature	-25	-	10	°C
Thermal conductivity	0.1	-	0.13	W/m.°C
Specific heat capacity	* 1.17e3	-	1.21e3	J/kg.°C
Thermal expansion coefficient	126	-	256	µstrain/°C
Processing properties				
Linear mold shrinkage	2	-	3.5	%
Melt temperature	191	-	288	°C
Mold temperature	80	-	90	°C
Molding pressure range	13.8	-	34.4	MPa
Electrical properties				
Electrical resistivity	1.7e20	-	1.5e21	µohm.cm
Dielectric constant (relative permittivity)	9.6	-	10.4	
Dissipation factor (dielectric loss tangent)	0.048	-	0.052	
Dielectric strength (dielectric breakdown)	10.2	-	11	MV/m
Comparative tracking index	600			V
Optical properties				
Refractive index	1.42			
Transparency	Translucent			
Absorption, permeability				
Water absorption @ 24 hrs	0.03	-	0.06	%
Water vapor transmission	0.746	-	1.4	g.mm/m².day
Permeability (O_2)	0.417	-	2.77	cm³.mm/m².day.atm
Durability: flammability				

Flammability	Self-extinguishing			
Durability: fluids and sunlight				
Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Acceptable			
Strong alkalis	Limited use			
Organic solvents	Acceptable			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Unacceptable			
Primary material production: energy, CO_2 and water				
Embodied energy, primary production	* 140	-	154	MJ/kg
CO_2 footprint, primary production	* 6.69	-	7.4	kg/kg
Water usage	* 472	-	522	l/kg
Material processing: energy				
Polymer molding energy	* 17	-	18.8	MJ/kg
Polymer extrusion energy	* 5.76	-	6.37	MJ/kg
Coarse machining energy (per unit wt removed)	* 0.892	-	0.986	MJ/kg
Fine machining energy (per unit wt removed)	* 4.65	-	5.13	MJ/kg
Grinding energy (per unit wt removed)	* 8.82	-	9.74	MJ/kg
Material processing: CO_2 footprint				
Polymer molding CO_2	* 1.27	-	1.41	kg/kg
Polymer extrusion CO_2	* 0.432	-	0.478	kg/kg
Coarse machining CO_2 (per unit wt removed)	* 0.0669	-	0.0739	kg/kg
Fine machining CO_2 (per unit wt removed)	* 0.348	-	0.385	kg/kg
Grinding CO_2 (per unit wt removed)	* 0.661	-	0.731	kg/kg
Material recycling: energy, CO_2 and recycle fraction				
Recycle	True			
Embodied energy, recycling	* 49	-	49.5	MJ/kg
CO_2 footprint, recycling	* 1.47	-	1.48	kg/kg
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 13.3	-	14	MJ/kg
Combustion CO_2	* 1.34	-	1.41	kg/kg
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Typical uses

Chemical process industry - pipes, bearings, pipe fittings, wire insulation, batteries, chemical laboratory apparatus, heat-shrinkable tubing e.t.c

Note

Values marked * are estimates

Fluorinated Ethylene Propylene (FEP)

General properties

Designation

Fluorinated ethylene propylene (Unfilled)

Density	2.12e3	-	2.17e3	kg/m^3
Price	3.25e3	-	4.93e3	NGN/kg

Tradenames

Dyneon

Composition overview

Composition (summary)

Copolymer of hexafluoropropylene and tetrafluoroethylene

Base	Polymer			
Polymer class	Thermoplastic : semi-crystalline			
Polymer type	FEP			
Polymer type full name	Fluorinated ethylene propylene			
% filler (by weight)	0			%
Filler type	Unfilled			
Composition detail				
Polymer	100			%
Mechanical properties				
Young's modulus	0.336	-	0.353	GPa
Compressive modulus	* 0.336	-	0.353	GPa
Flexural modulus	0.55	-	0.653	GPa
Shear modulus	* 0.117	-	0.122	GPa
Bulk modulus	* 0.949	-	0.997	GPa
Poisson's ratio	* 0.432	-	0.45	
Shape factor	3.6			
Yield strength (elastic limit)	* 14.9	-	17.1	MPa
Tensile strength	18.6	-	21.4	MPa
Compressive strength	* 14.4	-	15.9	MPa
Flexural strength (modulus of rupture)	* 26	-	30	MPa
Elongation	250	-	330	% strain
Hardness - Vickers	* 4.5	-	5.1	HV
Hardness - Rockwell M	* 29	-	31	
Hardness - Rockwell R	40	-	50	
Fatigue strength at 10^7 cycles	* 7.02	-	9.12	MPa
Fracture toughness	* 1.49	-	4.18	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.113	-	0.119	
Impact properties				
Impact strength notched 23 °C	190	-	200	kJ/m^2
Impact strength unnotched 23 °C	* 190	-	200	kJ/m^2
Thermal properties				
Melting point	264	-	286	°C
Glass temperature	* 81	-	96	°C
Heat deflection temperature 0.45MPa	* 119	-	161	°C
Heat deflection temperature 1.8MPa	* 49	-	82	°C
Maximum service temperature	196	-	215	°C
Minimum service temperature	-205	-	-195	°C
Thermal conductivity	0.242	-	0.261	W/m.°C
Specific heat capacity	1.01e3	-	1.05e3	J/kg.°C
Thermal expansion coefficient	83	-	105	µstrain/°C
Processing properties				
Linear mold shrinkage	3	-	6	%
Melt temperature	289	-	404	°C
Mold temperature	50	-	200	°C
Molding pressure range	34.4	-	138	MPa
Electrical properties				
Electrical resistivity	3.3e23	-	3e24	µohm.cm
Dielectric constant (relative permittivity)	2	-	2.2	
Dissipation factor (dielectric loss tangent)	2.85e-4	-	3.15e-4	
Dielectric strength (dielectric breakdown)	19.7	-	23.6	MV/m
Optical properties				
Refractive index	1.34	-	1.35	
Transparency	Transparent			
Absorption, permeability				
Water absorption @ 24 hrs	0.005	-	0.01	%
Water vapor transmission	0.101	-	0.244	g.mm/m².day

Permeability (O_2)	98.1	-	119 $cm^3.mm/m^2.day.atm$	
Durability: flammability				
Flammability	Non-flammable			
Durability: fluids and sunlight				
Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Good			
Oxidation at 500C	Unacceptable			
Primary material production: energy, CO_2 and water				
Embodied energy, primary production	* 155	-	171	MJ/kg
CO_2 footprint, primary production	* 7.78	-	8.6	kg/kg
Water usage	* 554	-	612	l/kg
Material processing: energy				
Polymer molding energy	* 19.9	-	22	MJ/kg
Polymer extrusion energy	* 5.86	-	6.48	MJ/kg
Coarse machining energy (per unit wt removed)	* 0.542	-	0.599	MJ/kg
Fine machining energy (per unit wt removed)	* 1.15	-	1.27	MJ/kg
Grinding energy (per unit wt removed)	* 1.82	-	2.01	MJ/kg
Material processing: CO_2 footprint				
Polymer molding CO_2	* 1.49	-	1.65	kg/kg
Polymer extrusion CO_2	* 0.44	-	0.486	kg/kg
Coarse machining CO_2 (per unit wt removed)	* 0.0407	-	0.0449	kg/kg
Fine machining CO_2 (per unit wt removed)	* 0.0859	-	0.0949	kg/kg
Grinding CO_2 (per unit wt removed)	* 0.136	-	0.15	kg/kg
Material recycling: energy, CO_2 and recycle fraction				
Recycle	True			
Embodied energy, recycling	52.3	-	52.9	MJ/kg
CO_2 footprint, recycling	1.57	-	1.59	kg/kg
Recycle fraction in current supply	0.672	-	0.742	%
Downcycle	True			
Combust for energy recovery	False			
Heat of combustion (net)	* 4.69	-	4.92	MJ/kg
Combustion CO_2	* 0.859	-	0.903	kg/kg
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Typical uses

Valves: electrical components, batteries, equipment for chemical plant, e.t.c

Note

Values marked * are estimates.