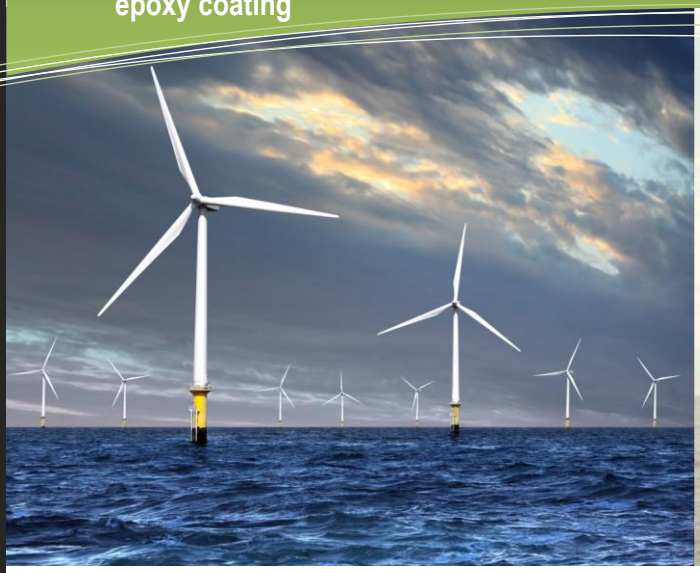
Life Time Windmill Monopile and Supporting Structure Exterior Corrosion Protection with 100% PVDF FLUOROSEAL® Coating

- **>1000X better corrosive salt-fog, salt-spray and sea water immersion barrier than epoxy coating**



"Protection of metals from corrosion is a topical issue affecting all areas of the world's economy. The losses due to the damage associated with marine transport corrosion during the period of construction or operation constitute approx. 50–80 billion USD and approx. 3 % of world GDP. Statistics show that 90% of ship failures are attributed to corrosion"
https://www.researchgate.net/publication/324045191_Corrosion_and_Wear_Analysis_in_Marine_Transport_Constructions

To be effective in protecting the steel monopile and other supporting structures from corrosion damages, the coating must meet the following requirements:

- Field applicable coating onto the large areas of exposed structures both above and below waterline by roller or brush or spray coating method and "cure" at ambient.
- The coating must be itself resistant to UV exposure for more than 50 years: so that the protection coating does not need constant maintenance. The coating should also block UV from reaching underneath the coating to prevent UV damages to the structural coating on the structure.
- The coating must have ability to block moisture penetration. Lesser moisture penetration will prevent the water pockets to be accumulated inside the ship hull coating interface. Lesser moisture also reduces the possibility of Cl-, Na+ and other salt ions being carried along to cause corrosions.
- The coating should have the ability to block corrosive gases such as CO_2, H_2S from carried by the moisture or penetration and react with the retained waters inside the coating-steel interfaces.
- FLUOROSEAL® coating with PVDF molecular structures are proven to provide the highest barrier capabilities of field applicable coating.

Wind energy will reach the historic milestone of 1 TW of installed capacity by 2023. By 2024, GWEC expects onshore wind to pass the 100 GW annual installations mark, while offshore wind will install more than 25 GW in a single year for the first time in 2025. Compared with onshore wind power, the offshore wind turbines are more concentrated. More than 99% of the total global offshore wind turbines are installed in Europe and the APAC regions.

Offshore wind turbines monopiles and other supporting structure are coated with epoxy and other coatings both inside and out for corrosion protection. The outside corrosion vulnerability depends on the environment that the wind turbines are located. More vulnerabilities to corrosion are faced by turbines that are located near sea where UV exposure is intense and salt-fog and salt-spray that damages the epoxy or other protective coatings.

FLUOROSEAL® 100% PVDF field applicable coating is a patent-pending technology developed by AIT Coatings of AI Technology, Inc. to provide life-time corrosion protection for the exterior and interior of the wind turbines.

For the exterior of the steel monopiles and mechanical support structures, FLUOROSEAL® 100% PVDF coating is impervious to salt water, salt-spray and salt-fog to provide unparalleled protection against both physio-chemical and microbiological bacteria induced corrosion. As top coating over existing epoxy coating or direct coating over steel, the special molecularly engineered 100% PVDF coating have proven to provide more than 100 times more effectiveness in preventing corrosion.

For the interior structure and electronics and mechanical infrastructure inside the nacelle, FLUOROSEAL® PVDF provides similar corrosion protection as conformal coating and sealants.

Steel bars coated with a gray and white epoxy coatings from commercial sources are partially coated with field applicable, patent-pending CPC7550 100% PVDF top coat (~50µm thickness). The portion protected by epoxy coatings only when exposed to salt-water (water with dissolved corrosive ions) suffered extensive corrosion in 65 days under the accelerated conditions of 60°C-5% saline solution. By comparison, epoxy coated steel when top coated with field applicable 100%PVDF coating showed no sign of corrosion. The accelerated conditions are roughly equivalent to 2-3 years of ambient temperature seawater submersion condition. That is, CPC7550 dramatically extend the operational time for ship at sea by years without needs for dry-docking.

Unparalleled Windmill Steel Support and Reinforced Concrete Corrosion Protection with 100% PVDF FLUOROSEAL® Coating

❖ >100X corrosive barrier than epoxy coating at 1/10 of thickness

The steel structures in support of the wind turbines subject to mechanical and corrosion stresses. Those that are located close to the sea of offshore are particularly vulnerable. They are often caused by water laden with corrosive ions such as chlorides, sulphates, and microbiological bacteria. Epoxy coatings are not adequate as barrier to these corrosive elements.

Monopile and Supporting structures built with steel are traditionally protected by paints of all kinds. Epoxy and/or polyurethane are predominant among them:

- Epoxy-Polyurethane molecules are vulnerable to UV degradation
- Epoxy-Polyurethane are molecularly porous with high permeability to moisture laden with corrosive acidic and ionic elements.
- Exterior of above ground storage tanks are vulnerable to UV and corrosion failure:
  1. UV induced molecular damages of epoxy-polyurethane coating to allow direct exposure of steel to corrosion.
  2. Gradual penetration of corrosive ions and/or acidic gases laden moisture.
- Interior of storage tanks are vulnerable to corrosion failure by:
  1. Gradual penetration of corrosive ions and/or acidic gases laden refinery atmosphere
  2. Under deposits such as water laden with chlorides, sulphates, and other corrosive acidic solutes.
  3. Microbiological bacteria and other bio-elements

FLUOROSEAL® PVDF Coatings:

1. Field Applicable Ambient Storage 1-Component VOC Compliant Coating
2. Apply Over the Existing Epoxy or Polyurethane Coatings
3. Air Drying to Clear Overcoat
4. Air-Drying, 100% PVDF top coating CPC7650 and CPC7550 for interior protection
5. Proven corrosion protection <75µm coating thickness
6. Proven UV blocking to protect the underlying epoxy-polyurethane
7. Proven moisture and rain barrier
8. Proven barrier to biological

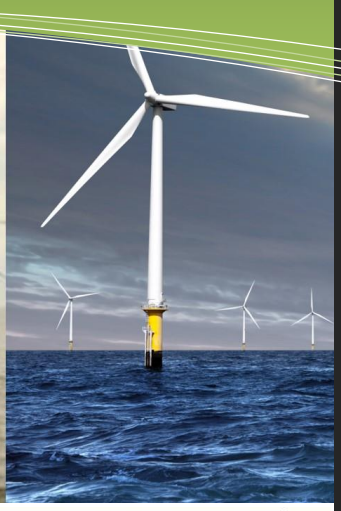
PHYSICAL CHARACTERISITCS OF FLUOROSEAL® PVDF Corrosion Protection Coatings

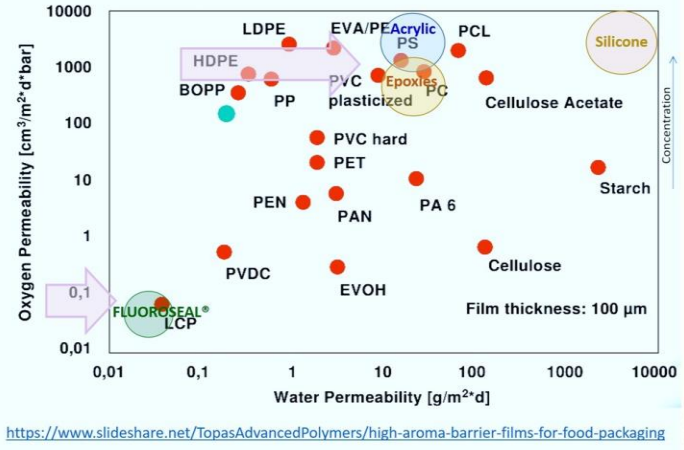
	CPC 7150	CPC 7650	CPC 7550
SPECIAL ATTRIBUTES	1) Transparent, flat finish 2) Primerless, VOC-Exempt Coating 3) Roller-Brush or Spray 4) Corrosion & antifouling	1) Transparent, flat finish 2) Primerless, VOC-Exempt Coating 3) Roller-Brush or Spray 4) Chemical and bacteria induced corrosion	1) Corrosion + Antifouling 2) Field Applicable 100% PVDF Protection 3) Roller or Spray 4) VOC Exempt Coating
WATER-MOISTURE PROPERTIES	STANDARD AND CONDITIONS (@25ºC)		
Water Absorption (D570) %	<0.01 (Typical Acrylic: >0.4)	<0.01 (Typical Acrylic:>0.4)	<0.01 (Typical Acrylic:>0.4)
Water Permeability (gm.mm/m².d) @ 1atm	0.0009 (Typical Acrylic: >5.2)	<0.0009 (Typical Acrylic: >5.2)	<0.0009 (Typical Acrylic: >5.2)
Percentage of PVDF (%)	>70%	100%	100%
THERMAL PROPERTIES	STANDARD AND CONDITIONS (@25ºC)		
Glass Transition Temp (Tg,ºC)	-45	-45	-45
"Melting Point" (ºC)	>120	>120	>120
CTE (Coefficient of Thermal Expansion, ppm/ºC)	95	75	80
Thermal Conductivity (BTU-in/hr-ft²-ºF)	1	1	1
Thermal Decomposition (ºC)	>350	>350	>350
MECHANICAL PROPERTIES	STANDARD AND CONDITIONS (@25ºC)		
Hardness (Shore D)	50	60	50
Tensile Modulus (Psi/Mpa)	40000/(275)	200,000/(1,375)	180,000/(1,238)
Flexual Modulus (Psi/Mpa)	30,000/(206)	150,000/(1,031)	135,000/(928)
Tensile Elongation (%)	300	100	300
OPTICAL PROPERTIES	STANDARD AND CONDITIONS (@25ºC)		
Refractive Index (D542)	1.43	1.43	1.43
ELECTRICAL PROPERTIES	STANDARD AND CONDITIONS (@25ºC)		
Dielectric Strength (KV/mil)	0.8	0.8	0.8
Volume Resistivity (ohm-cm)	$1.8x10^{14}$	$1.8x10^{14}$	$1.8x10^{14}$

Splash, Above and Below Sea Level Windmill Corrosion Protection with 100% PVDF FLUOROSEAL® Coating

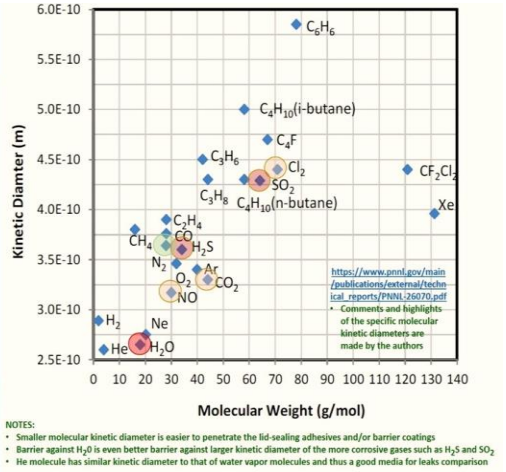
- >1000X better salt-spray, salt-fog, and seawater barrier than epoxy coating
- Minimizing and Easy in Cleaning of Biofouling for submerged segment

AiT COATINGS

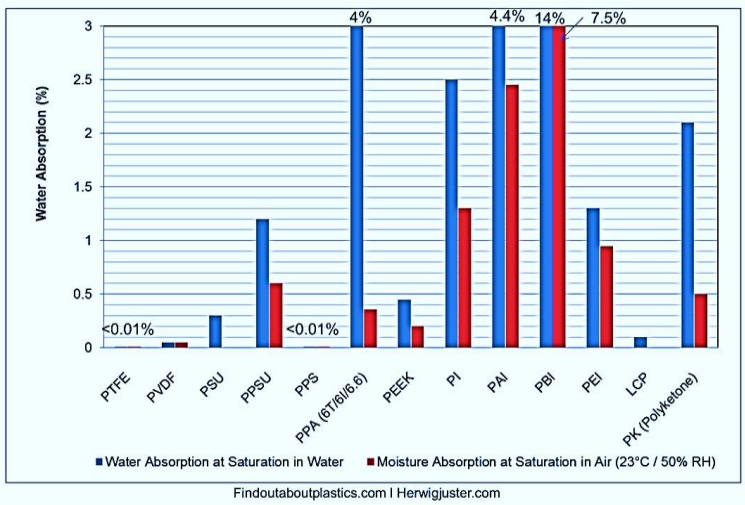


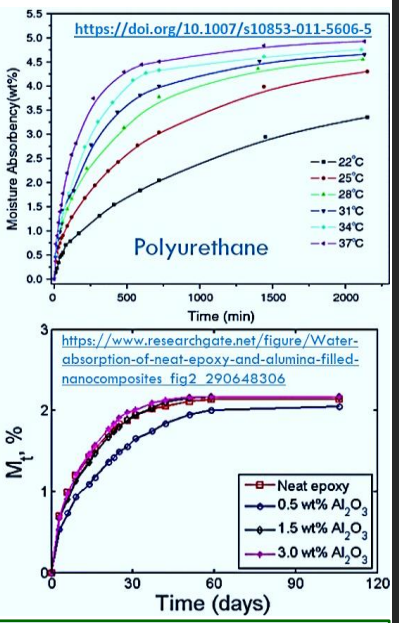


https://www.slideshare.net/TopasAdvancedPolymers/high-aroma-barrier-films-for-food-packaging



FLUOROSEAL® PVDF is one of most densely molecularly packed coating to most effective in blocking H_2O moisture and O_2 that are the smallest kinetic diameter and thus orders of magnitude lower in permeability to the exhaust corrosive gases such as CO_2, H_2S, SO_2, NO, CO, Cl_2, etc., when compared to other traditional polymer coatings.





Besides having the highest capability in blocking moisture ingression (least moisture permeability), FLUOROSEAL® PVDF is molecularly packed to absorb and retain the least amount of water among all common coating polymers.

UV and Corrosion Protection Coating for Corrosion Protection:

"Protection of metals from corrosion is a topical issue affecting all areas of the world's economy. The losses due to the damage associated with marine transport corrosion during the period of construction or operation constitute approx. 50–80 billion USD and approx. 3 % of world GDP. Statistics show that 90% of ship failures are attributed to corrosion"

https://www.researchgate.net/publication/324045191_Corrosion_and_Wear_Analysis_in_Marine_Transport_Constructions

- Blocking moisture laden with carbonic acid from CO_2, other acidic gases and salt ions is key in reducing to eliminating these deleterious factors.
- Blocking moisture and acidic and corrosive gases from penetrating inside the concrete further stop corrosion and chemical reaction weakening.
- In comparison to epoxy, polyurethane and alkyd coatings, FLUOROSEAL® PVDF coatings are molecularly engineered to have several orders less moisture absorption and lower in moisture and corrosive gases permeability to provide an effective sealing.
- FLUOROSEAL® sealing coating have 5B crosshatch and outstanding shear-bond strength to provide protection even in the more stringent environment.
- Coatings with low Tg molecular structure for stress absorption and proven extreme weathering cycle and exposures.
- FLUOROSEAL® PVDF sealing coatings are VOC-exempt for brush, roller and spray coating anywhere.

Sealing Against Corrosion Leakage and Electronic Corrosion with 100% PVDF FLUOROSEAL® Coating

- Impervious to salt-fog and corrosive gases penetration
- >100X corrosive gases and moisture barrier than epoxy coating at 1/10 of thickness
- Sealing oil and lubricant leakages from seams of mechanical enclosures

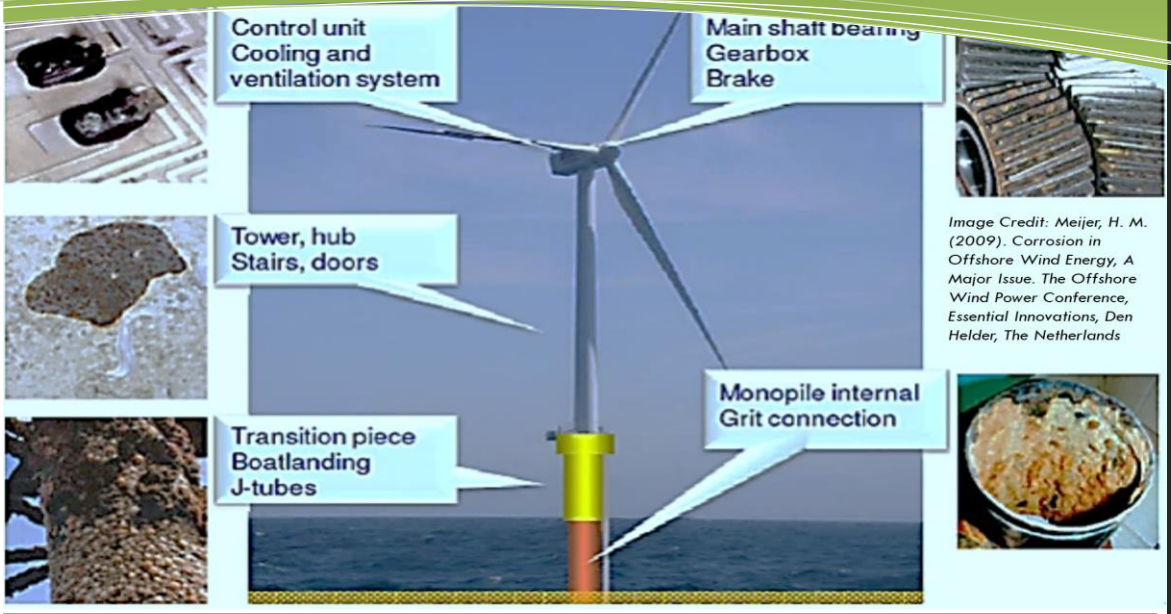


Image Credit: Meijer, H. M. (2009). Corrosion in Offshore Wind Energy, A Major Issue. The Offshore Wind Power Conference, Essential Innovations, Den Helder, The Netherlands

The table below summarizes the critical properties of FLUOROSEAL® Corrosion Protection Coating

Properties Required for Effective Protection of Steel Structures	Polyurethane	Epoxy	FLUOROSEAL® Coatings (CPC 7550, Clear, UV Blocking for Storage Tank & Pipeline Exterior) (CPC 7650 for Storage and Pipeline Interior)
Moisture-Water Permeability (Relative Ingress Number, g/m²*d)	High (>20)	High (>20)	Very Low (<0.05)
Corrosive Gases (e.g. H_2S, C_2O, etc.) Permeability ($cm^3/m^2*d*bar$)	Very High (>2,000)	Very High (>2,000)	Very Low (<0.1)
Water Repellant	Fair	Fair	Good
Water Absorption (Retention)	Medium	Medium	Low
UV Molecular Stability (Resistance)	Fair (Proven <10 Years)	Fair (Proven <10 Years)	Outstanding (Proven >60 Years)
Choices of Color	1. Colored 2. Customized	1. Colored 2. Customized	1. Clear 2. Customized
Field Application Method	Spray, Brush, Roller (1-or 2-Component, Ambient Storage, Coating Liquid)	Spray, Brush, Roller (1-or 2-Component, Ambient Storage, Coating Liquid)	Spray, Brush, Roller (1-Component, Ambient Storage, VOC Exempt, Coating Liquid)
Cost of Material and Labor	Similar for material and Labor for the same performance level (Thicker: >200 Micron)	Similar for material and Labor for the same performance level (Thicker: >200 Micron)	Similar for material and Labor for the same performance level (Thickness: 50 Micron)

About AI Technology, Inc. and AIT Coatings Division:

With the introduction of FLUOROSEAL® concrete and corrosion protection coating solutions (patents pending), AITCOATINGS Division builds on the modified PVDF technology to provide field applicable high fluoropolymer protection for stopping weakening of concrete buildings and infrastructure. As top coatings, FLUOROSEAL® corrosion protection coatings can extend existing coated steel structures years more maintenance free services.

AIT develops and manufactures its product in two separate ISO 9001:2015 certified facilities totaling over 100,000 sq ft on a 16 and 18-acre in New Jersey, USA. AIT also has worldwide sales operations along with service centers in Africa and China. Since pioneering the use of flexible epoxy technology for electronic packaging in 1981, AI Technology (AIT) has been one of the leading forces in developing advanced materials and adhesive solutions for electronic interconnection and packaging with more than 30 patented technologies.

Capabilities in blocking moisture laden with salt ions, dissolved corrosive gases, and UV resistance, FLUOROSEAL® PVDF coating also seals and impervious to lubricant and fuel leakage:

- Direct coating over coated or bare steel surfaces will protect the steel structure both above and below the seawater line for years without corrosion.
- Applying the FLUOROSEAL® to the existing coated steel monopiles and supporting structures exterior will **"arrest" and stop the further corrosion damaging effects from the weathering.**
- In the case of steel structure at the splash zone, 100%PVDF FLUOROSEAL® provides unparalleled corrosion protection to physio-chemical and stress induced corrosions.
- The low surface energy and the unparalleled ability in blocking corrosive gases generated by micro and bacteria growth have been proven to provide reduction of growth for fouling microorganism outside of the mechanical structure submerged in seawater.

Sealing Against Oil and Fuel Leakages:

- PVDF FLUOROSEAL® coating on seams of enclosure also seal against lubricants and other fuels from leaking to cause potential fire hazard.

AI Technology, Inc. (© 2024, V2.1) | 70 Washington Rd., Princeton Junction, NJ 08550, USA and
18 Roszel Rd, Princeton, NJ 08540, USA Tel: +1-609-799-9388 | www.aitcoatings.com | www.aitechnology.com | ait@aitechnology.com