# Cathodic Protection Cables with PVDF Barrier Layer for Use in Harsh Environments

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**A general discussion on cathodic protection as a method for corrosion control, with specific focus on why PVDF is the preferred barrier material for harsh environment cathodic protection cables.**

A basic corrosion cell requires an anode, a cathode, an electrolyte and a connecting conductor[1]. Galvanic corrosion is a common corrosion mechanism that occurs when two different metals are placed in the ground. The soil functions as an electrolyte because it contains moisture and salt ions. The presence of a conductor between the two metals can result in a galvanic current flowing from the anode to the cathode. As a result of this galvanic current, the anode begins to corrode and the cathode will have metal or hydrogen plated on it, but it does not corrode[2]. This continuous process is the general theory behind cathodic protection (CP) systems, which protect metal structures by making them act as the cathode of the corrosion cell. **Figure 1** shows a general corrosion cell.

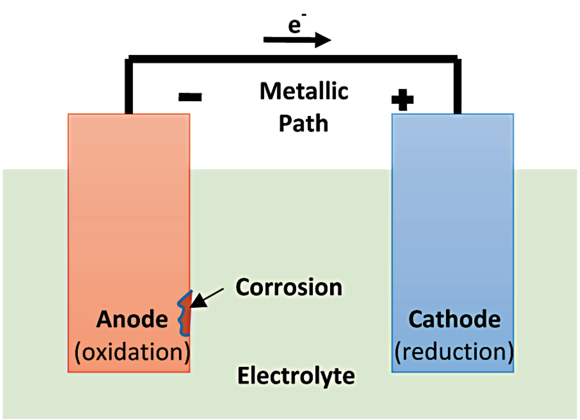


**Fig. 1 — A typical corrosion cell.**

## Cathodic Protection (CP)

One method of corrosion control is by using a CP system. The CP system is a critical component when designing processes with exposed metal surfaces. Both soil and water can function as electrolytes, so CP systems are typically limited to direct burial or underwater structures. Passive cathodic protection systems operate by relying on a sacrificial anode, which is defined as a metal with a more negative electrical potential than the metal structure that it is protecting. After the sacrificial anode fully corrodes, it is replaced with a new anode, and the protected metal system continues to operate without corroding. For metal systems spanning great distances like steel pipelines, passive cathodic protection cannot economically protect the system, so impressed current cathodic protection systems are used. In these impressed current systems, a DC current is typically applied from an external power source.

It is important to note that secondary reactions of underwater impressed current CP systems can produce brominated and chlorinated oxidants, including but not limited to, hypochlorous and hypobromous acids, hypochlorite and hypobromite, chloro and bromo-organics, chloride and bromide, chloramines and bromamines. The general reaction, which produces these oxidants is associated with the reduction of chloride or bromide ions in water to form Cl2 and Br2[3].

Both passive and impressed current cathodic protection systems depend on copper cables to act as the connecting conductor, which completes the corrosion cell circuit. Besides this functional role, cathodic protection cables must withstand extreme environmental conditions. Some geographical locations present climatic challenges that require a CP cable jacket with a wide range of service temperatures. For direct burial cables, the CP cable jacket must be durable to resist the abrasive forces of dirt, rocks and sand. In both underwater and underground applications, CP cables can be exposed to chemicals across a wide pH range, so excellent chemical resistance is required. For outdoor applications, it is critical that the CP cable jacket can withstand exposure to ultraviolet radiation without degradation. Different CP applications may require different degrees of cable flexibility, so a suitable CP cable jacket material needs to have a wide flexibility range.

## Cathodic Protection Cable Design

Depending on the application, CP cable jacket designs commonly use: (a) a single layer of high molecular weight polyethylene (HMWPE), or (b) an inner fluoropolymer barrier layer of PVDF or ECTFE with an outer jacket of HMWPE. **Figure 2** shows a typical CP cable construction.

**Fig. 2 — A typical CP cable construction with a PVDF barrier layer and HMWPE jacket[4].**

HMWPE is very resistant to physical forces like installation, abrasion and crushing, making it a useful cable jacket material for direct burial CP applications. A common source of failure in direct burial cables comes from the presence of moisture or mechanical forces interfering with the copper conductor, which can be minimized with an HMWPE jacketed CP cable.

When corrosion occurs primarily through chemical exposure like in underwater CP applications, HMWPE is not always chemically resistant enough to protect the copper conductor. A common CP cable design for harsh chemical environments uses PVDF or ECTFE as an inner barrier layer because these fluoropolymers are extremely chemical resistant. As an added layer of protection against mechanical forces, the fluoropolymer barrier layer is protected by an outer jacket of HMWPE. This type of design ensures that the CP cable remains chemically resistant even in an environment with harsh mechanical conditions.

Depending on the selected polymer cable jacket, CP cable producers may also crosslink the polymer jacket, which can increase chemical and thermal resistance as well as abrasion resistance.

The rest of this article discusses the specific properties of PVDF and why these properties make PVDF the preferred barrier material for harsh environment cathodic protection cables.

## PVDF Chemistry

Polyvinylidene fluoride (PVDF) is a semi-crystalline, melt processable thermoplastic in the fluoropolymer family. Unlike some other fluoropolymer materials such as polytetrafluoroethylene (PTFE) or fluorinated ethylene propylene (FEP), PVDF is only partially fluorinated. PVDF is made up of repeating monomers of vinylidene fluoride (VF2). As is shown in **Figure 3**, the chemical composition of the PVDF monomer consists of a two carbon backbone with two fluorine atoms bonded to one carbon atom, and two hydrogen atoms bonded to the other carbon atom. Ethylene chlorotrifluoroethylene (ECTFE) is also shown for comparison. Like PVDF, ECTFE is partially fluorinated. PVDF is one of the lowest-cost fluoropolymers.

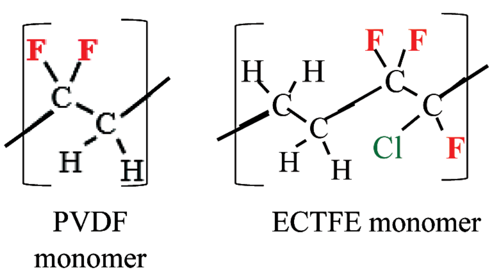


**Fig. 3 — Chemical composition of PVDF monomer (left) and ECTFE monomer (right).**

## Mechanical Properties

Many of the high performing properties of PVDF result from the nature of its carbon-fluorine bond, which is one of the strongest chemical bonds that exists. PVDF homopolymer, which is made up of only repeating VF2 monomers, has the highest tensile strength out of all the fluoropolymers.

PVDF homopolymer is mechanically strong, but it is also rigid, so for CP cables requiring increased flexibility, PVDF copolymers are used. The comonomer hexafluoropropylene (HFP) is reacted with the VF2 monomer, and the resulting PVDF copolymer has increased flexibility, better resistance to stress cracking and robust chemical resistance. Varying the amount of HFP co-monomer in the polymerization reaction results in a wide range of PVDF flexible grades, which makes them suitable for a variety of CP cable designs.

Abrasion resistance is a key requirement in CP cables, which can face abrasive forces from installation and sand erosion. Both PVDF homopolymers and copolymers have excellent abrasion resistance as summarized in **Table 1**. This abrasion data was collected using a Taber abrasion test. The value reported is milligrams of material abraded from the sample in a set period of time, so a lower value indicates better abrasion resistance.

**Table 1. Abrasion Resistance of PVDF and Various Other Polymers[5].**

| Materials | mg loss |
|---|---|
| Kynar® PVDF | 5-10 |
| Polyamide 6-10 (nylon) | 5 |
| PVC (Rigid) | 12-20 |
| Polypropylene | 15-20 |
| CPVC | 20 |
| HDPE | 25 |
| 304 Stainless Steel | 50 |
| Mild Steel | 100-300 |
| PTFE | 500-1000 |

Abrasion resistance can be further increased by crosslinking the PVDF. Exposing PVDF to e-beam radiation results in the formation of crosslinks between different chains in the polymer. Crosslinking of PVDF provides several advantages: (a) increase in maximum service temperature up to 175°C; (b) increase in abrasion resistance; and (c) increase in chemical resistance.

Not all fluoropolymers exhibit an increase in material properties when they are cross-linked. Some fluoropolymers undergo chain scission and lose mechanical properties. Some CP cable producers prefer to crosslink their cables for better barrier properties so PVDF performs well in these CP cable applications.

## Thermal Properties

Select PVDF grades have a *UL RTI* rating of 150°C (302°F), meaning they can operate continuously at 150°C without significant loss of mechanical properties. In cold weather applications, select PVDF grades can pass cold impact testing at -60°C (-76°F). PVDF and select PVDF copolymers have a melting point around 167°C, which allows easy processing on standard extrusion equipment, providing an opportunity for cost savings associated with capital investment. There is no need for high-temperature extruder barrels or expensive exotic metal screws. PVDF also has the widest processing range of all the fluoropolymers.

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## Chemical Resistance

Fluoropolymers in general are known for their excellent chemical resistance to a wide variety of acids, solvents and bases. For cable jacketing, PVDF homopolymer has a broad chemical resistance from a pH of less than 1 to a pH of 13. PVDF copolymers used in cable jacketing are resistant to chemical attack from a pH of much less than 1 up to 13.5. Specifically, PVDF has outstanding resistance to strong acids like hydrochloric acid, nitric acid, and sulfuric acid, and halogens like chlorine and bromine.

**Table 2** summarizes the tensile strength at yield of a PVDF homopolymer grade (Kynar® 740) and copolymer grades (Kynar Flex® 2800, Kynar Flex® 2850) after a six month outdoor exposure to several different acids. None of the PVDF grades show significant reduction in mechanical properties after the six month test.

**Table 2. Tensile Strength at Yield of PVDF Grades in Six Month Outdoor Exposure[6].**

| Chemical | Kynar Flex® 2800 | Kynar Flex® 2850 | Kynar® PVDF 740 |
|---|---|---|---|
| Unexposed control value (psi) | 2,900-3,900 | 4,500-5,500 | 6,000-8,000 |
| Nitric acid (71% aq) | 3,100 | 5,000 | 6,400 |
| Hydrofluoric acid (49% aq) | 3,100 | 5,200 | 7,000 |
| Sulfuric acid (96% aq) | 3,100 | 4,900 | 6,600 |
| Hydrochloric acid (37% aq) | 3,200 | Not tested | 6,800 |
| Sodium hypochlorite (5% aq) | 3,100 | 4,800 | 6,500 |
| Acetic acid (50% aq) | 3,300 | 5,000 | 6,600 |

CP cables can face chemical exposure across the entire pH range. However there are also CP applications facing exposure to a limited pH range or perhaps only a handful of chemicals. If the cable is for continuous use in an environment having a pH greater than 12, ECTFE is normally considered as an alternative barrier layer to PVDF. For almost all other applications, PVDF is the preferred barrier layer since it provides exceptional performance, easier processing and lower raw material costs.

For applications facing exposure to strong acids, hydrocarbons and most solvents, PVDF will effectively resist chemical attack. PVDF is commonly used in the chemical processing industry to handle chemicals such as acids, halogens, hydrocarbons, slurries and solvents, and there are case studies of PVDF lined pipes still in operation after 15 years of continuous service exposed to chlorine[7].

Additionally, the PVDF is chemically resistant against the common chloro-oxidants and bromo-oxidants that are produced in the secondary reaction of impressed current CP systems. The designers of CP cable have an opportunity for cost savings by using PVDF as the barrier layer in a CP cable jacket. This is so because the PVDF is generally a lower-cost fluoropolymer.

## Outdoor Exposure

Some polymers degrade when exposed to ultraviolet (UV) radiation making them unusable outdoors, or they may require UV stabilizers or color pigmentation. PVDF is transparent to UV radiation, making it suitable for extended service in outdoor applications. PVDF is widely regarded in the architectural community as the coating resin with the best weathering resistance.

A 14 year study on PVDF coated panels in Florida has shown excellent color retention when compared to panels unexposed to UV radiation[8]. Additional tests have also been conducted on PVDF films, which were continuously exposed to direct Florida sunlight for five years, and there is no significant loss in mechanical properties of the films after five years[9].

Outdoor CP cables with a PVDF barrier layer should not experience any significant loss in PVDF mechanical properties when exposed to UV radiation.

## Conclusion

Cathodic protection remains a common method used in industry to control corrosion. When producing CP cables, proper material selection for the cable jacket and barrier layer is important to ensure extended cable service life, but also to save raw material and processing costs by not over specifying a material.

PVDF is a fluoropolymer with excellent mechanical properties, thermal, chemical and UV resistance. Because of its balanced high-performance properties and opportunity for cost savings, PVDF is a preferred material for the barrier layer in CP cable design.

For additional discussion on cathodic protection cables with PVDF barrier layer engineered for use in harsh environmental applications, contact the author at Arkema or visit the company's website listed below.

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