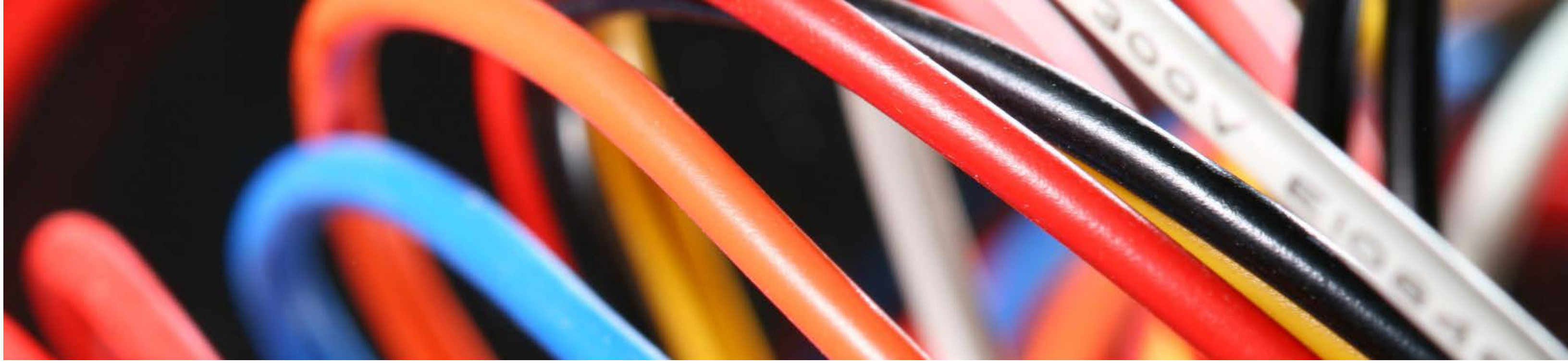
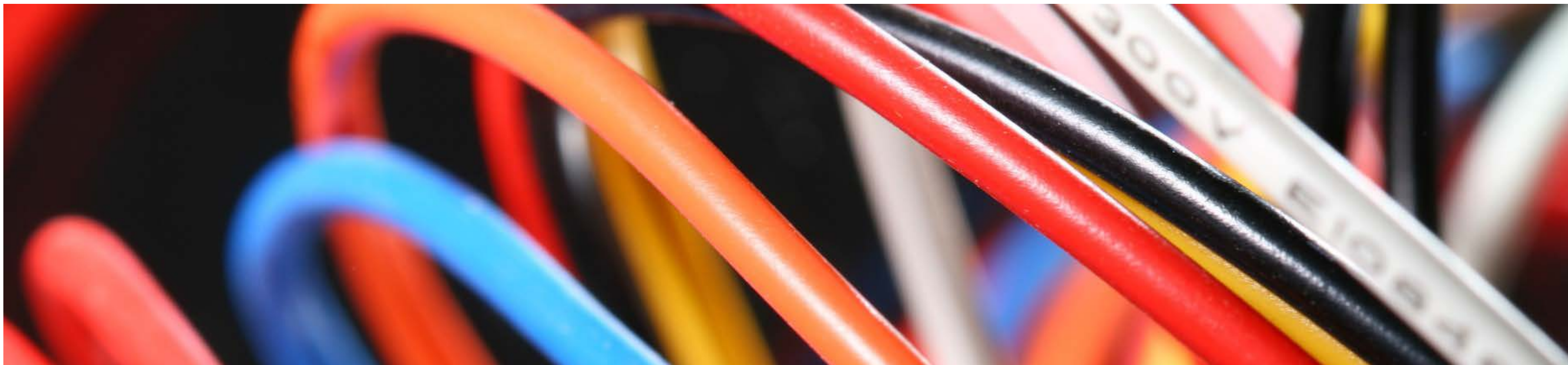


Ink adhesion on High Performance Wire & Cable Jacketing Materials

Enercon Industries Corporation



Plasma Treating Teflon® & other high performance wire & cable jacketing materials for ink adhesion

High performance wire & cable jacketing materials often have low levels of polar functional groups on the surface making them inherently resistance to traditional marking and coding methods. Many experiments have been conducted to investigate ways of improving adhesion to these types of materials. Environmental exposures introduce their own unique stresses which can push (or exceed) the limits of traditional bonding processes. Defining these materials, their surface characteristics, and the surface treatment-based mechanisms necessary for them to physically and chemically adhere to ink and coating interfaces, is critical to understanding how to optimize surface adhesions to jacketing substrates. This technical article will explore these challenges and the plasma technology recipes that are enabling ink adhesion.

Learn more about:

- **Surface Profiles of Challenging Substrates**
- **In-Line Plasma Surface Modification Techniques**
- **In-Line Plasma Treatment Recommendations by Jacketing Polymer Type**

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Introduction

It goes without saying that there are a significant number of wire and cable jacketing substrates used in high performance applications, such as those within the automotive and aerospace industries, which pose significant challenges to standard ink bonding techniques. Many of these substrates are "unprepared", meaning there has been no prior surface modification (or priming) before they are introduced to marking and coding processes. Wire and cable jacketing material are typically made from thermoplastics (PVC, ETFE, FEP, PP, TPE, PUR, etc), thermosets (CPE, CP, XLPE, EPDM, Si, etc) or fibrous coatings such as fiberglass or K-Fiber. All have low levels of polar functional groups on the surface and have poor wettability and adhesion properties, making it difficult to apply other functional layers such as inkjet inks, adhesives and coatings. Many experiments have been performed globally to investigate ways of improving adhesion to the materials used in wire and cable jacketing. Environmental exposures introduce their own unique stresses which can push (or exceed) the limits of traditional bonding processes. Defining these materials, their surface characteristics, and the surface treatment-based mechanisms necessary for them to physically and chemically adhere to ink and coating interfaces, is critical to understanding how to optimize surface adhesions to jacketing substrates.

Surface Profiles of Challenging Substrates

The type of marking or coding ink chosen for wire jacketing materials depends greatly on the surface energy of the substrate, and specifically whether the surface is polar or non-polar. Polar substrates will have a positive or negative charge and will adhere best to other polar inks and coatings. Non-polar substrates are charge-neutral and must rely on applied adhesion mechanisms, such as chemical, diffusive or mechanical bonding.

Thermoplastic olefins (TPO), for example are primarily non-polar because they are made of low polarity polyolefins such as polyethylene and polypropylene. TPOs are very difficult to print or coat, particularly with polar inks and coatings which are polyurethane- or acrylic-based, because these materials do not have charged molecules for surface interaction. As a result, the dried or cured ink or coating film can be removed easily from the surface. In order to print on TPO, a level of surface roughness combined with oxidation must be formed with surface treatment techniques.

Teflon® or polytetrafluoroethylene (PTFE) is a low-surface energy (low polarity) polymer used in high performance wire and cable jacketing applications. Because of it highly unique properties, PTFE presents many challenges to ink and coating manufacturers whose wire and cable customers desire to print on it. PTFE contains highly electronegative fluorine atoms, but due to its symmetrical arrangement around carbon atoms, its net dipole moment is zero. Hence, surface modification is necessary. PEEK or PolyEtherEtherKetone is another a high-performance, low polarity polymer jacketing material which is ideal in applications where high heat-resistance and dimensional stability are needed. Its high chemical resistance, however, presents significant ink adhesion challenges.

In contrast, more polar substrates such as polyurethanes are more conductive to printing and coating with acrylic- or polyurethane-based inks/coatings, for example which are also polar. When this combination of polar materials interface with each other, a strong dispersive force is created across the entire interface. In addition, the removal of other adhesion limiting factors such as surface contamination, and the addition of surface roughness, can further enhance ink and coating bond strength.

In-Line Plasma Surface Modification Techniques

There are a number of methods available for modifying substrates for printability. Among them are low pressure plasmas, infrared- and UV light- based exposures, ozone exposures, chemical primers, ion beam, gamma and X-ray exposure. However, these methods are costly to apply in terms of hardware, consumables, and due to their line speed-suppressing effects. In-line atmospheric plasmas, however, offer a high density treatment approach with a very low capital expenditure and operating costs. These techniques, in the form of blown ion plasmas, flame plasmas and variable chemistry(gas phase) plasmas, project charged electron and/or ion particles to material surfaces at energies and densities that are intended to exceed the bonding energies of the substrate surface. Applying the right atmospheric plasma at the proper power density can displace (abstract) surface atoms or electrons and promote free radical effects which can chemically modify the surface. In addition, surface cleaning and roughening can occur. Ultimately, the surface polarity is raised to improve the probability of ink wetting and adhesion. In fact, adhesion chemistry tells us that the better an ink wets out, the larger the surface area covered. This allows for more reactive groups interactions at the surface and a stronger bond.

Blown ion plasma technologies simply use air as its process gas to generate high positive ion velocities to create physical surface etching, cleaning and oxidizing surface effects. *Flame plasma* technologies entrain air with a hydrocarbon gas in precise proportions prior to combustion to form an intense blue flame. Flame impingement is used to polarize wire and cable jacketing materials with polar functional groups such as ether, ester, carbonyl, carboxyl, and hydroxyl which are contained in a flame plasma. Flame polarization and functionalization is made through reactive oxidation of a surface. *Variable chemistry plasma* treating systems generate an electrically charged atmosphere similar to blown ion air plasmas, but uses chemical atmospheres in place of air to introduce a wide range of surface modifications to a jacketing substrate. The systems are characterized by their generation of high density reactive species for low temperature material processing. The chemical plasma process can involve surface preparation via the breakdown of low molecular weight organic materials (LMWOM) and surface decontamination, fine etching of the surface to create new topographies, and the grafting of new functional groups or chemical species on the surface.

Plasma Treatment Prescriptions

Because the processing of jacketed wires and cables is typically in-line, or continuous, from surface activation through the adhesion of inks and coatings, Enercon's focus has been placed on determining the treatment effectiveness of different atmospheric surface activation systems on various polymer substrates rather than on long-term treatment degradation profiles. As such, analyses have been conducted pertaining to the post-treatment surface energies as created by air plasma, flame plasma, and atmospheric chemical plasma techniques, and measured by the use of dyne solutions and sterile cotton swabs. Tests were conducted within the Enercon surface treatment laboratory a typical line process speeds. As exemplified in Table 1, the application of appropriate atmospheric pressure plasma surface modification techniques can create a profoundly polarizing effect (higher surface energies as measure by dynes/cm) to very non-polar jacketing substrates.

Table 1. Plasma Treatment Effects on Common Jacketing Materials

Wire Jacket Material	In-Line Plasma Technology	$W/ft^2/min$	Pre-treat Dynes/cm	Post-treat Dynes/cm

Teflon	Atmospheric Gas-Phase Plasma	109	18.5	39
FEP	Atmospheric Gas-Phase Plasma	21.8	16-18	52
PVC	Flame Treatment	116.5	35	46
PVC	Atmospheric Ion Plasma	457.3	35	60+
Silicone	Atmospheric Ion Plasma	686	20-25	50+

Following years of similar test protocols, Enercon has been able to assemble a chart which recommends the in-line continuous plasma treatment technique(s) most appropriate for sufficiently polarizing the surface of non-polar polymer jacketing materials (see Table 2) for promoting coding and marking ink wettability and adhesion. High levels of reactive oxidation, surface roughening, and surface functionalization are the key contributors. Should there be an interest in evaluating any of these technologies for addressing ink and coating adhesion issues, Enercon's lab facilities can be leveraged to determine the precise plasma technique and power density to achieve long-term adhesion objectives.

Table 2. In-Line Plasma Technology Recommendations by Jacketing Polymer Type

Wire/Cable Polymer Properties & Treatment Chart								
Polymer Reference	**Chemical Name**	**Mechanical**	**Thermal**	**Electrical**	**Chemical**	**Native Dynes/cm**	**Treatable Dynes/cm**	**Recommended Technology**
PTFE	polytetrafluoro-ethylene	Good dimensional stability. High rate of creep.	Excellent -180° to 260°C	Excellent	Excellent	18.5	40-60	Atmospheric gas-phase plasma
FEP	fluoroethylene-propylene	Good dimensional stability. High rate of creep.	Excellent -190° to 205°C	Better	Excellent	16-18	50-60	Atmospheric gas-phase plasma
PFA	perfluoralkoxy	Better. High rate of creep. Low resistance to abrasion.	Excellent -150° to 260°C	Better	Excellent	17	50-60	Atmospheric gas-phase plasma
ETFE	ethylene-tetrafluoro-ethylene-copolymer	Excellent. High tensile strength and impact strength.	Better -100° to 150°C	Excellent	Good	25	40-50	Atmospheric gas-phase plasma
ECTFE	ethylene-chlorotrifluoro-ethylene	Excellent abrasion resistance.	Better Maximum continuous use at 150°C	Excellent	Excellent	31	50-60	Atmospheric gas-phase plasma
PCTFE	polychloro-trifluoroethylene	Excellent low creep.	Better -250° to 150°C	Good	Excellent	31	40-60	Atmospheric gas-phase plasma

PVF	polyvinyl-fluoride	Excellent abrasion resistance.	Good	Good	Good	28	40-50	Atmospheric gas-phase plasma
PI	polyimide	Excellent high tensile strength.	Excellent, especially at high temps.	Excellent	Better	40-50	50-70	Atmospheric gas-phase plasma
PEI	polyetherimide	Excellent low shrink.	Better	Better	Excellent	40-45	50-60	Atmospheric gas-phase plasma
			Continuous use at 180°C					
PEEK	polyetherketone	Excellent especially at high temps.	Excellent	Excellent	Better	34-36	60	Atmospheric Ion Plasma / Atmospheric gas-phase plasma
			Continuous use at 250°C					
PPS	polyphenylene sulfide	Excellent	Better. Continuous use at 200°C	Better	Excellent	38-40	60-70	Atmospheric Ion Plasma / Atmospheric gas-phase plasma/Flame
PSU	polysulfone	Better retains properties over a wide thermal range.	Better. Continuous use at 200°C	Good	Better	41	60-70	Atmospheric Ion Plasma / Atmospheric gas-phase plasma/Flame
LCP	liquid crystal polymer	Excellent	Excellent	Good	Excellent	33-37	60	Atmospheric Ion Plasma / Atmospheric gas-phase plasma