"Manufacturing Europe 1993", Sterling Publications Ltd.

Non-stick, water repellent protective coatings

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A novel family of non-stick inert coatings, under the trade name Kiss-Cote, can be applied to any material to protect the surface from moisture corrosion and chemical or biological fouling and prevent water, ice, mildew, paint and biological waste from adhering to treated surfaces. The gas permeable coatings are also tolerant to extreme temperatures and pressures. Their potential is outlined in this article.

The physical and chemical properties of a surface determine how it interacts with the environment. The more stable it is, the less it interacts with the environment. The non-aesthetic purpose of a coating is to stop a surface from interacting with what comes in contact with it.

The very characteristics that make inert materials desirable also make them difficult to handle and apply. How can a non-reactive material be bonded to a surface?

Slightly reactive materials, such as PTFE, can be bonded using surface etching, heating, primers and pressure - all of which are costly — some with limited success. These materials have poor wear resistance and are prone to migrate, causing unwanted contamination of surrounding materials. Silicones, especially poly(di-methyl siloxane), are the most inert and chemically stable materials known to man. They are so non-reactive that they cannot be bonded to a surface.

A new catalytic process can make these highly inert polymers partially reactive. The resulting Kiss-Cote material has a reactive side of the polymer which forms a very secure bond with the substrate while its inert outer surface is both passive and resistant to chemical and environmental attack.

Surface protection

Traditionally, two distinct approaches have been taken in the development of surface protection:

1. *Ablative surfaces* sacrifice external performance to improve appearance. These self-polishing surfaces are removed by weathering or wear and can vary in texture and colour.

2. *Non-reactive or inert surfaces* have advantageous non-stick fouling-release characteristics and are not prone to environmental attack. But the inert materials are difficult to apply as a coating that bonds to a substrate.

Silicone development

During the Second World War silicones were developed as lubricants and insulators for submarines and high-altitude aircraft due to their ability to withstand extremes in temperature and pressure in a variety of environments. Silicone rubber is still the most inert and chemically stable material.

Attempts at developing a non-stick coating have had to address the paradox that the quality that makes such a coating desirable – its lack of reactivity – also makes it hard to apply. Most non-stick coatings are susceptible to cracking and de-lamination or become worn down with exposure.

In the past, researchers have attempted to incorporate inert materials like silicone or Teflon into other coatings as a matrix or binder, hoping that low levels of the stable material would aggregate along the surface of the cured coating. Results were disappointing. Adding silicone to a paint usually turns the material into a non-paint, and the material quickly peels away from the substrate.

Mixing with other materials such as binders and fillers also diminishes the inert material's beneficial characteristics, and the performance of the coating may only be enhanced for a short time. The binders introduce other problems. For example, they are usually rigid with a different coefficient of expansion than the surface of the substrate. With fluctuations in temperature, the coating expands and contracts at a different rate than the underlying material, causing the coating to crack and de-laminate.

The primary objective of Kiss-Cote technology was to develop a coating that presents a completely inert face to the environment yet is securely bonded to the substrate it protects. The chosen polymer, poly(dimethyl siloxane), is one of the most non-reactive silicones known.

The critical step was to develop a catalytic process to make part of the polymer chain reactive, so that a secure bond could form between the coating and the substrate. The chosen polymer is resistant to most chemicals, provides a non-stick surface and can only be removed by taking away the surface layer of the substrate to which it is bonded.

Silicone rubber manufacture

The manufacture of silicone rubber involves extensive cross-linking between chains of a polymer. As the reaction proceeds, the sites on each chain react with each other, forming a highly cross-linked network of polymer. Silicone rubber is made by letting this cross-linking reaction proceed until all the reactive sites are linked.

Kiss-Cote materials are made by a patented process that modifies the polymerisation process. Inhibitors are added to the polymer to halt the cross-linking process prematurely at a pre-selected point. This leaves many highly reactive sites on the polymer chain available for bonding to the substrate. The non-reactive side of the cross-linked chain forms the inert face with the un-reacted sites reacting with the substrate to bond the inert layer to it.

This family of materials is a uniquely formulated type of surface treatment with most of the properties of the silicone-base polymer: temperature, pressure and chemical resistance and water-repellent capabilities; yet it sticks to surfaces and will not migrate.

The key attributes of this treatment at each interface depend on surface phenomena. The intermediate material — between the reactive bonding component, and the inert surface, which provides protection – has no value and should be minimised. Correctly applied, this surface treatment is a mono-molecular layer approximately 120 Angstroms (0.012μ) thick.

The coating adapts to the surface of the substrate and causes no major changes in the coated product.

Surface chemistry

The chemical reactivity of a material is related to its surface energy. Materials with a low surface energy tend to be non-reactive. Materials with a high surface energy tend to be very reactive. Kiss-Cote has a very low surface energy – 20-22 dynes/cm^2.

The contact angle measurement is the height or angle of the bead of the fluid as it contacts the surface. The contact angle of a material to water and other fluids relates to its reactivity.

Reactive surfaces readily wet or sheet with water as they have a low contact angle to it. Non-reactive surfaces do not react well with water, and have a high contact angle. Reactive surfaces are hydrophilic (water-loving) and non-reactive materials are hydrophobic (water-hating).

Kiss-Cote modified poly(dimethyl siloxanes) are non-reactive and inert. They exhibit a well-organised methylated surface layer. Their surface energy is low and coated surfaces are hydrophobic. Unlike PTFE, they do not wet as well with most other liquids as with water, so treated surfaces are non-stick with a fouling-release character.

Drag reduction and lubricity

When a solid is at rest in a fluid its boundary layer is stationary, for the same reason that water along the bank of a stream does not move. When relative movement occurs between the solid and the fluid there is resistance, which is related to the visco-elastic characteristics of the fluid and the molecular forces at the solid/fluid interface, which bind the boundary layer to the surface. This resistance, or drag, results in a shear force which is transmitted through the boundary layer to the surface of the solid.

The stability of the boundary layer, at a molecular level, depends upon the relationship between the force that binds the fluid molecule to the surface of the solid and the kinetic energy of the free molecules in the fluid stream. A proportion of the drag arising from the relative movement of the solid and the fluid is dependent on surface chemistry interactions occurring at the interface between the solid object and the fluids moving against its surface.

The inert Kiss-Cote treatment is used to lubricate coated surfaces, reducing surface friction and drag with a non-stick finish. Laboratory and field tests of the lubrication capabilities of the coatings have only just begun. Early evidence demonstrates that they increase the wear cycle and lifetime of treated wear parts, particularly those in sliding contact with one another.

For example, Lightfield Ammunitions Incorporated coated the front end of projectiles and reported a 10 per cent increase in exit muzzle velocity. These coatings have also been used to improve performance of many record-setting and world championship power and sailing boats since 1986.

Most conventional lubricants and mould release agents are slippery and they separate because of interfacial shear between the molecules of the lubricant or release agent. They do not affect the solid surfaces they lubricate. Kiss-Cote based lubrication and release agents operate on a different concept: The coating changes the properties – including the friction coefficient – of the solid material itself. Coated surfaces require smaller amounts of lubricants and less frequent lubricant changes than non-coated surfaces.

A Kiss-Cote lining protects any type of mould from most acids, bases, solvents, and detergents. The non-stick finish permits multiple releases without re-application. When the mould is separated the release agent does not transfer to the finished parts, so contamination and migration do not occur.

The quality of protection provided by the Kiss-Cote treatment depends upon:

1. A stable substrate which can withstand the mechanical stresses of the environment in which the product functions
2. As smooth a surface as possible to prevent mechanical retention of fouling materials, and
3. A substrate surface which is non-reactive to gas vapour. The surface treatment is resistant to most acids, alkalis, solvents and detergents. It is hydrophobic (non-wetting), but is vapour-permeable. Therefore, susceptible substrate surfaces should be pretreated to prevent corrosion caused by gaseous agents.

Impact

The family of coating products is expected to have a broad impact on dozens of industries. The coatings will be applied to a range of materials for different reasons, at varying stages of the manufacturing process.

This innovative surface treatment has marine, automotive, aviation, construction, power generation, ammunition and weaponry, computer and electronic, consumer goods, medical and dental applications. It serves as a high-performance mould release, a lubricant and lubricant additive.

These chemical- and corrosion-resistant, water-repellent, gas-permeable inert coatings can be applied to virtually any material to serve any or all of the following purposes:

Protecting the coated material from moisture, corrosion and chemical or biological fouling

Lubricating the coated surface by reducing surface friction and drag and, when used as an additive, improving the slipperiness and temperature stability of other lubricants or surface treatments

Preventing unwanted substances – water, ice, mildew, paint, natural or man-made detritus – from adhering to treated surfaces

Polishing and preserving metal, wood, resin and ceramic surfaces, serving as a replacement for high-gloss wax

Sealing equipment and structures subjected to repeated heat and freeze cycles and keeping treated surfaces dry.

Keeping water off one side of a treated surface while allowing vapours (including water vapour) from the dry side to pass out.

These new coatings share most of Teflon's desirable performance characteristics, but few of its liabilities. They are easier to apply and require no pre-application treatments or post-application curing. Polymers are non-toxic, non-volatile and environmentally friendly. In addition, if the coating is damaged in use, it can easily be repaired.

Dr Keith Kent is chairman of Kiss-Cote Incorporated, of Tampa, Florida, USA, a silicone coatings manufacturer; and of Kent Integrated Scientific Systems Incorporated, a research and development company specialising in scientific and biomedical materials and devices, and industrial problem solving. He also has US and foreign patents on new families of silicones and other polymers.