Functional and smart coatings

In the third of his series of six articles on coatings, Prof. A S Khanna, Retd. IIT Bombay, Chairman SSPC India, addresses functional and smart coatings. Functional coatings correctly describe its utility for a particular paint application. It is also possible to manufacture a coating based upon the function required for a particular substrate or surface.

Introduction

From the basic definition of paint coatings, they are generally used to improve the aesthetics of a surface, or its corrosion protection. However, there are several examples in industry, where the requirements cannot be met by these two simple nomenclature. So the term functional coating has been introduced which not only covers these two basic functions but also performs an additional specific function. In fact, the best way to explain a functional coating is that it enhances the functional capability of a paint coating. Thus, a functional coating, as the name suggests, is designed and used to solve a particular functional issue of a substrate.

There are several examples to illustrate various functions:

- Resistance from some strong chemicals
- Water repellency – hydrophobic surface
- Scratch and abrasion resistance
- Anti-reflection coatings
- Solar heat reflection coatings
- Making the surface conductive
- Anti-glare and anti-fog coatings
- Water proofing of a surface
- Anti-graffiti property in the coating
- Anti dust pickup
- Anti-microbial and anti fouling coatings

Functional coatings are a type of materials that can be specifically designed for a variety of applications in which they must be able to carry out a defined function or range of functions. They can be organic, inorganic, or hybrid. In countless applications that are part of our daily lives, there are numerous functional coatings. Functional coatings are used on a variety of products, including household furnishings, automobiles, laptops, mobile phones, solar panels, and more complex items like orthopaedic implants and medical equipment, invisible paints, radars, and satellites. More recently, the term "smart coating" has been used to describe functional coatings that can react to specific stimuli brought on by either intrinsic or external events. It is also possible to combine some of these functions to carry out more than one function in a coating [1-3]

Science and technology of functional coating

How functional coatings differ from the so-called conventional coatings? Are they altogether different coatings with different composition, including polymers, pigments or additives or they use different concept of synthesis and formulation technology? Answer is both. In some cases, the base polymer needs to be very rugged and robust, in other cases, a specific combination of pigments and additives works, while in a few cases, special concept of surface properties is undertaken. For example, a highly corrosion resistant coating with long durability can be created by just changing a basic epoxy with a phenolic epoxy which resists corrosion and enhances durability due to better cross-linking and rigidity. Another method of enhancing corrosion resistance is to add special pigments such as MIO, or glassflakes in epoxy, which enhance the permeability resistance of the coating.

Type	Two Pack		
Mixing Ratio	Base: Hardener- 4:1		
Induction time	10 Minutes		
Pot Life	4-5 hours (@30 °C & 65% RH)		
Composition	Epoxy resin with suitable hardener fortified with nano particles		
Volume solids	80% ± 5%		
Application		Nozzle orifice	Nozzle pressure
	Brush	---------	------------
	Conventional spray	1.5-3 mm	3-4 kg/cm^2
	Airless spray	0.53-0.68mm	Not less than176 kg/cm^2
Recommended DFT	150-1000 microns (based upon various applications)		
Theoretical Spreading Rate	@ 100 microns DFT 8 Sqmt per Lt		
Drying time	Surface: 4-5 Hrs (@30 °C & 65% RH) Hard Dry: Overnight (@30 °C & 65% RH)		
Over coating	Min 24 hr at max 7 days (@30 °C & 65% RH)		
Color	Grey and any inert shade / aluminum		
Finish	Semi Glossy to eggshell		
Thinner (MP Thinner)	Brush: 0-5% Conventional Spray: 8-10% Air less Spray: 0-3%		

Chemical Resistance against fumes and spillages:	Acid	Alkalis	Solvents	Salt water	Fresh water
	Excellent	Excellent	Excellent	Excellent	Excellent
Temperature Resistance:	up to 250°C				
Weatherability:	Excellent with a suitable top coat				
Flexibility:	Very Good				

Fig. 1: Technical Data Sheet of an epoxy based nano coating whose function is to resist a steel surface from highly acidic or alkaline environment

Another very recent method is to add nano-particles which enhance corrosion resistance and mechanical properties to an extreme level. Very recently, we made an acid resistant coating from a basic epoxy by adding very special nano-particles which provided us a coating which can resist any acid (sulphuric, hydrochloric or nitric), any alkali or solvent. It passed almost seven days continuous immersion test in each, 50% sulphuric acid, 10% hydrochloric and 10% nitric acid, 10% sodium hydroxide etc. and 4000h of salt spray test. Also, its temperature resistance increased from a normal 110°C to 250°C. Figure 1 shows the Technical Data Sheet of this coating. Its functionality suits especially for battery pit in ships and submarines or for pickling plants and for refineries and petrochemical plants [4].

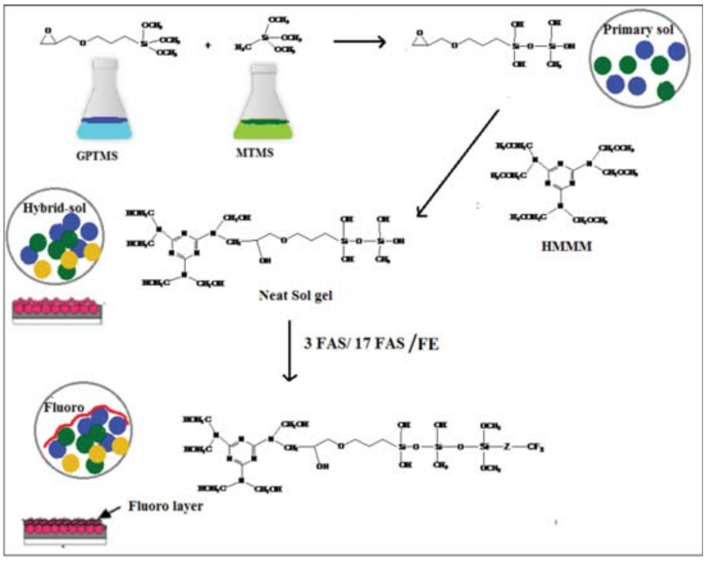

Fig. 2a: Formation of epoxy precursor using Sol-gel process followed by reaction with a fluro-based resin to give saturated coating

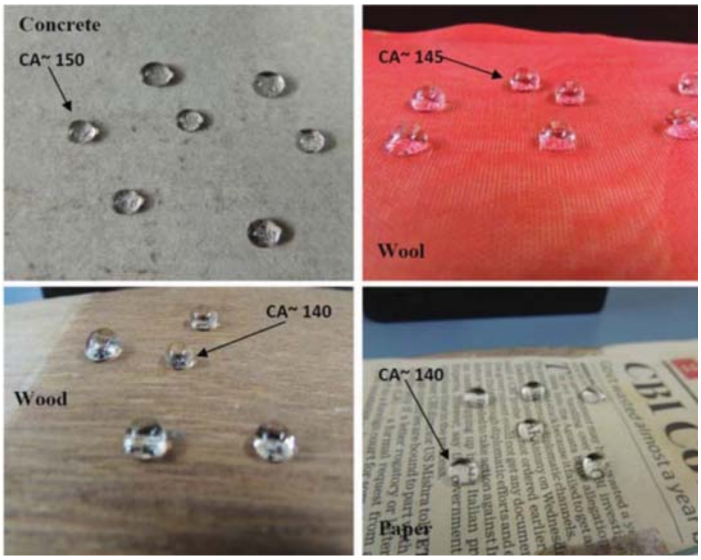

Fig. 2b: Hydrophobicity on glass, cloth, wood and paper substrate [5]

Hydrophobic coating

Let us now illustrate the example of a functional coating which is the base for several important functions in paint coatings, such as water repellence, self-cleaning, anti-glow coatings etc. The first step is to develop a hydrophobic coating. The hydrophobic coatings are defined as those in which a water drop makes a minimum contact with the surface, which is determined by the angle of contact the water drop makes with the surface. If the contact angle is more than 90°, it is called a hydrophobic coating.

Coatings with contact angle lower than 90° are classified as hydrophilic coatings while those having contact angle more than 150° are called super- hydrophobic or oelo-phobic coatings.
The first step in making a hydrophobic coating is to create a low energy coating, also called a well saturated coating surface having minimum reactivity to the environment. For this, the resin must have a C-F bond. A demonstration of the synthesis of such a coating using Sol-gel process is given in Figure. 2a.
An epoxy base precursor is formed using a Si-based sol (MTMS) which is allowed to react with an epoxy resin having at least one OH group in the chain. This is then reacted with an amine to create good cross-linking, followed by reaction with a fluro-based resin. Such a coating results with hydrophobic properties as shown in Figure 2b. However, to make this coating self-cleaning, the surface roughness of the coating needs to be reduced as well as to create a lower sliding angle. This is achieved by reacting it with nano-particles such nano-ZnO or nano-Silica, which makes these water drops slide over the surface resulting in self-cleaning. A very interesting self-cleaning coating, effective on glass, cloth, plastic, wood or concrete surface was made successfully [5].

Self-healing coating

The next example is the development of self-healing coatings. Many coatings even having a long design life, crack with time due to excessive weathering conditions such as extreme sunlight, rain or snow or natural climate change during hurricanes and strong wind conditions. These small cracks further

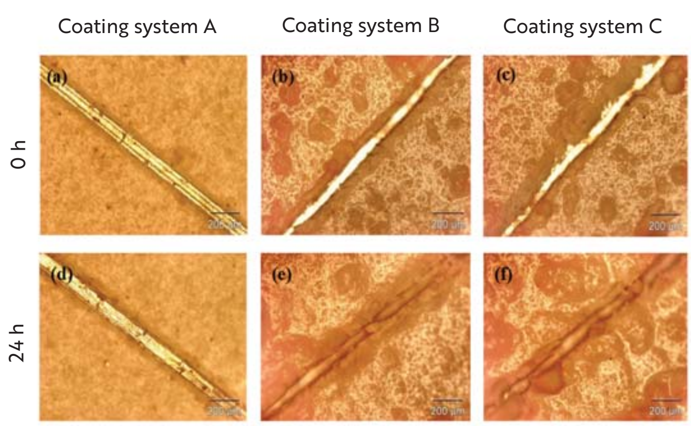

Fig. 3a: Example of self-healing coating in which the paint system was modified by the addition of micro-spheres containing healing material (linseed oil) in two different concentration resulting in varying time for healing for the scratch made

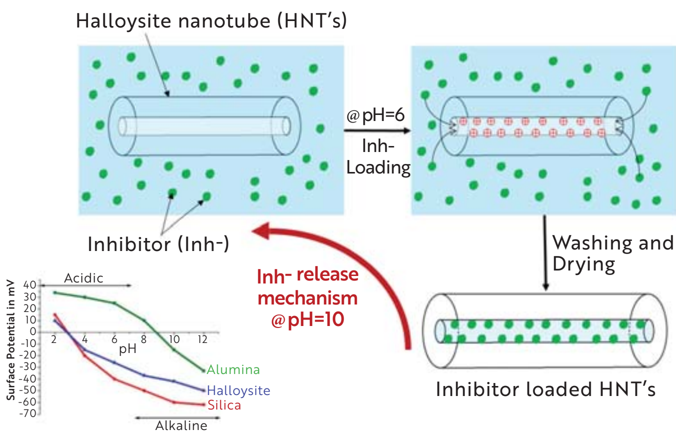

Fig. 3b: Example of self healing being controlled by Halloysite nanotube containing inhibitors which release on change in pH during cracking and heal the crack [6]

Fig. 4a: Lightning which can destroy an aeroplane part where it falls

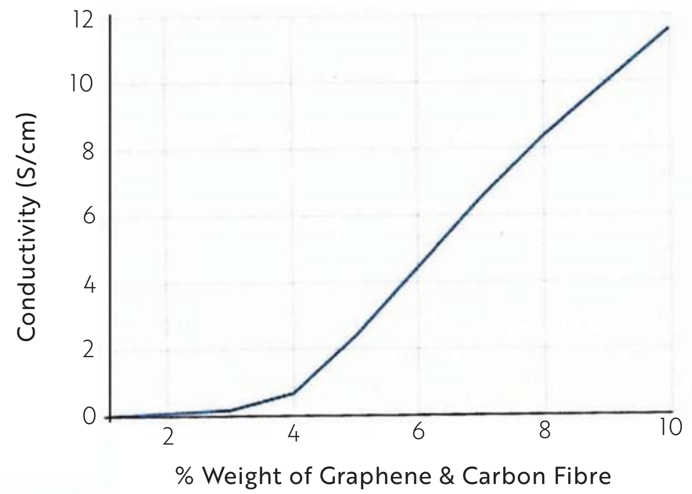

Fig. 4b: Results of the conductive coating developed by optimizing the graphene, carbon fiber and carbon nanotubes

damage the coating leading to re-application of coating. Self–healing helps to bridge the small cracks thus formed, leading to the repair of such damages. This exactly works on a similar principle of crack or cut formed on our skin due to some bruise or cut, which automatically cures due to the presence of curing cells in our blood. Method of self-healing is basically similar, if the equivalent of natural cells in blood are added in the paint formulation right in the beginning of its manufacturing. There are two important methods of creating such cells, which hold the anti-corrosion or healing material which has tendency to heal the crack. It is possible to make the anti-corrosive material enclosed in small microspheres using the anti-corrosive material, being exposed in a rotating system which allows the anti-corrosive material stored in these spheres acting as the healing material and reach immediately to the broken or cut paint area and heal it immediately. In the second approach, Halloysite nano-tubes, were used to hold the healing material. These nano-tubes hold them at a particular pH and release them if this pH changes. So when a paint coating is damaged due to some abrasion or scratch, the pH at this point changes, resulting in the release of healing material at the spot, leading to the cure of the crack. Such coatings were developed by us and an example of healing process is shown in Figure 3a and Figure 3b.

Conductive coating

Another important example of a functional coating is to make a conductive coating. Usually organic coatings are insulating coatings which are responsible to cut the flow of electrons and thereby reduce the corrosion of metal substrate. However, there are several examples where a partial conductivity is needed on the coated surface, such as for anti-static coatings or coatings which spread the electrical charge very quickly over the whole component surface. A very special application is the development of a conductive coating for aeroplane skin to counter the damage due to lightning during thunderstorm (Figure 4a). For such applications, a conductivity of more than 5S/cm is required. There are many formulations, which use conducting polymers like polyaniline (Pani), polypyrrole (PPy), polythiophene, which provide adequate conductivity and protection against corrosion for aluminum alloys [7]. One major drawback with these conducting polymer materials is their low solubility and fast

About the Author

Dr. A S Khanna, a retired Professor from Indian Institute of Technology, Bombay, after 27 years of teaching and research, guiding 27 Ph.D's, 125 Masters and creating research expertise in High Temperature Corrosion, Coatings, Surface Engineering, Corrosion of concrete structures and nano-coatings. He has won several International Awards such as Humboldt Fellowship from Germany, Royal Norwegian Fellowship from Norway, Fellow of Japan Key Centre and worked as visiting Professor in Germany and France. He has written three books and edited four books. He has published more than 300 papers in several International and National Journals with more than 4500 citations. He is a coating expert and is associated with Hindustan Zinc for several assignments related to galvanization and its applications, Sterling & Wilson for selection of sites for solar power plants, oil & gas industry for consolation on coatings for underground pipelines and offshore structures.
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disintegration. A very recent method of making conductive coating is by the addition of graphene. The unique 2D structure of graphene combined with the free pi electrons of C atoms; make graphene a highly electrically conductive material (more than copper). Other carbon allotropes like carbon nano-tubes (CNT) also possess high conductivity. We made such kind of coating for Boeing aeroplane. The coating was made using 5% of graphene, 5% of carbon fibers and 2% C nano-tubes (Figure 4b). The coating formed showed a conductivity of 3S/cm [8] but did not possess good mechanical properties.

In the same way one very important coating made was to create the anti-glare and anti-fog function to avoid accidents during driving due to glare from vehicles coming from opposite side. In the same way anti-fog function helped in avoiding fog on spectacles. Detailed information is available in the patent [9].

Conclusions

Functional coatings correctly describe its utility for a particular paint application. It is also possible to manufacture a coating based upon the function required for a particular substrate or surface. The paper describes a few important functional coatings. The manufacturing of functional coatings can depend upon the type of resin to be used, a combination of different pigments and additives or by using nano-additives. This description helps to understand the proper utility of protective coatings.

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