Using optically-active additives to help protect and preserve structures

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Despite advances in surface preparation, improved materials and more stringent quality regimes, corrosion is still a major economic issue. A study in 2001 concluded that the direct cost of corrosion in the USA was \$279 billion per year, which is approximately 3% of the US gross domestic product.¹ In the UK, the Hoar Report estimated in 1971 that the cost to the nation's economy was between 3 and 4% of GDP per year. A more recent survey by the Institute of Materials, Minerals and Mining² concluded that the cost to the UK economy was 2 to 3% of GDP per annum.

The challenge faced by owners, managers and operators, as well as paint manufacturers and applicators, is how to properly protect key structures and survey them for three key criteria: coating integrity, corrosion and early failure. Many structures contain relatively large spaces which are difficult to inspect and exhibit defects which are very hard to detect (see Figure 1). A coating that can be more easily inspected will improve coating integrity and aid safety. A practical system is now in use to improve the inspection of coating applications on a wide range of substrates. This is based around an additive that responds to particular wavelengths of ultraviolet light and enables inspections to be carried out at distances of around 3 metres, thereby speeding up inspection and making defects easier to detect. Surveying large areas of coated surfaces through remote methods allows for considerable time and safety improvements in the inspection process both at new constructions and during repairs.

The purpose of an optically-active additive (OAA) is to make a coating react to UV light. This effect permits quick, noninvasive inspections of very large coated areas during the application process, allowing the inspector to identify and concentrate on defective areas, thus reducing inspection time while assuring the probability of good application and coverage.

It works by highlighting holidays and pinholes, areas of over- and underapplication, as well as giving the

Figure 1: Corrosion in dark corners: coatings failure can have severe cost implications



opportunity for defect detection and identification of early coating deterioration throughout the lifetime of the system. It can be said that improved first-time coating quality will improve coating performance.

The physics of luminous technology

If a single photon approaches an atom which is receptive to it, the photon can be absorbed by the atom in a manner very similar to a radio wave being picked up by an aerial. At the moment of absorption the photon ceases to exist and the total energy contained within the atom increases. This increase in energy is usually described symbolically by saying that one of the outermost electrons 'jumps' to a 'higher orbit'.

This new atomic configuration is unstable and the tendency is for the electron to fall back to its lower orbit or energy level, emitting a new photon as it goes. The entire process may take no more than 1 x 10^{-9} seconds. The result is much the same as with reflective colour, but because of the process of absorption and emission, the substance emits a glow.

According to Planck,³ the energy of each photon is given by multiplying its frequency in cycles per second by a constant (Planck's constant, 6.626 x 10⁻²⁷ erg seconds). It follows that the wavelength of a photon emitted from a luminescent system is directly related to the difference between the energy of the two atomic levels involved.

In terms of wavelength, this relationship is an inverse one so that if an emitted photon is to be of short wavelength (high energy), the gap to be jumped by the electron must be a large one. The numerical relationship between these two aspects is the inverse of Planck's constant. Chemical engineers are able to devise molecules with these energy levels in mind, so as to adjust



the wavelength of the emitted photons to produce a specific colour.

A concept with a long history

As long ago as 1609, Brand discovered a substance which glowed in air and called it phosphorous, thus giving rise to the term 'phosphorescence'. Scientific investigation of inorganic phosphors only began in the 19th century. Work was carried out by Becquerel, Lenard, Stokes and Verneuil, amongst others.

In 1887 Verneuil identified the contribution which heavy metal impurities had in the luminescence of inorganic materials.⁴ There are several types of luminescence; the significant one for coating purposes is photoluminescence. This process can be divided into two main categories:

- Fluorescence where the interval between absorption and emission is short, say less than one ten-thousandth of a second (ie there is no appreciable afterglow).
- Luminescence where the interval between absorption and emission is long (potentially days) and there is an appreciable afterglow.

Both processes are used in optically-active coating systems (OACS) and can be formulated to give specific responses to UV light. Therefore, a range of optically-active coatings can be developed to meet almost any colour requirements.

Inorganic versus organic OAAs

There are two common types of opticallyactive additives available commercially: inorganic and organic.

- Inorganic OAAs exhibit large particle sizes of 5 to 10µm (no mobility), are light-stable, can have a choice of colours as shown in Figure 2, are useful in a wide range of coating systems, and are more expensive.
- Organic OAAs require low addition levels, are soluble in solvents and organic liquids (mobile), are blue under UV (emitting the same colour as lint, oil, grease etc), can fade quickly, have limited use in a range of coating systems and are less expensive. They are also indistinguishable from old tar epoxy-type coatings still seen on some structures and vessels.

Figure 3 shows two coatings each containing OAA: inorganic on the left and organic on the right. Each is illuminated by ultraviolet light. The effects of overcoating and subsequent migration of the organic OAA through the topcoat are also shown, again using UV illumination. This effect can be seen within a very short period of time (minutes) or can take a longer time to develop (weeks) as is the case with the solvent-free systems shown in Figure 4.

This illustrates solvent-free coatings to MIL-PRF-23236C⁵ with no OAA (centre of panel), with inorganic OAA (left) and organic OAA (right), which were cured for 28 days, then overcoated with another similar solvent-free coating but with no OAA. After a further 28 days, the organic Figure 3: Optically active coatings containing inorganic additive (left) and organic (right) illuminated by UV light (a) after application, (b) after overcoating with a clear topcoat, (c) after 25 minutes, showing migration of the organic OAA through the topcoat.



OAA (right on panel) had migrated through into the second coat.

Both inorganic and organic types react to UV light in the same way. They convert the wavelength of the UV light and then reflect it in the visible range. Organic OAAs tend to convert into the blue visible region of wavelengths whereas inorganic OAAs can convert into a range of colours. As blue is the natural emission colour for a wide range of materials – grease, oil, fibres etc – there can be a tendency for the detection of false positives if organic OAAs are used. It is best to use a non-natural emission colour such as yellow/green (see Figure 5), which is possible using inorganic types.

Figure 4: Migration through a solvent-free topcoat takes place over an extended period in the case of organic OAA (right side of panel) but does not occur with inorganic OAA (left side); the central strip on the panel contains no OAA





Traditional coating and inspection techniques

At present a typical specification for coating would be as follows:

Two coats of 125mm dry film thickness (DFT) of an epoxy-based anticorrosive are applied, the system being of the 'hard' type. In addition, two stripe coats of paint can be applied on the edges. These edges are normally required to be rounded using mechanical means during construction. Single-coat systems with very high dry film thickness are also available. The inspection regime adopted is as follows:

- inspection of surface cleanliness and degreasing before commencement of surface preparation;
- inspection after surface preparation to ensure correct surface cleanliness has been achieved;
- inspection of wet film thickness (WFT) during application;
- inspection of dry film thickness (DFT) of the first coat of the system application;
- inspection of stripe coating;
- inspection of final coat and acceptance.

This process is therefore labour- and timeintensive. Inspection is carried out by visual means, wet and dry film thickness measurement, and by low-voltage wet sponge testing. The drying time between coats dictates throughput and surface inspection can take up to 15% of the total coating time. Even with this level of inspection, failure is still commonplace from factors such as:

- poor coating specification;
- poor surface preparation;
- over-application;
- under-application;
- exceeding the coating application envelope.

The inspection process is reliant on the need for close contact with the structure, making 100% inspection difficult if not impossible to achieve.

The use of optically-active additives (OAAs) allows better, faster, easier and more thorough inspection of the coating by enabling coating defects to be identified at a distance, and hence improving the quality of the inspection process while offering reduced inspection time.

Manufacturing, coating and inspection using OAA

An optically-active additive (OAA) is added to existing and established coatings, as manufactured by the major paint companies, at a low level (1%) which has no appreciable effect on the coating performance.

The OAA is incorporated by the paint manufacturer during the manufacturing process. Testing to date by all the major manufacturers indicates that there is no degradation in coating performance. The

addition of an OAA is similar in effect to that of a coloured pigment addition.

Coating and inspection methods

The surface to be coated is cleaned and inspected in the normal manner. The first coat containing the optically-active additive is applied using a UV light to monitor application when wet, which is feasible since the technique is optical. Missed areas can be 'repaired' at this stage. Once dry, the first coat is inspected using the same UV light.

The procedure should follow normal inspection procedures carried out by an inspector. However, as the light will detect defects such as pinholes at a distance of up to 3 metres, large areas can be scanned quickly without the need for close access, considerably reducing inspection time. The benefits increase as the inspector becomes familiar with the system and becomes more confident with the results from the system. Any areas of under-application are readily identified and remedial work carried out as appropriate. The second coat containing no optically-active additive is applied and the inspection process is repeated.

Identification of defects

At the inspection of the first coat, areas of under-thickness or defects will show up as 'black' spots or areas of decreased glow under the UV light. Areas of high film build are brighter than areas of low film build. At the inspection of the second coat, areas that are holidays will show the original first coat as bright areas or pinholes through the second coat. Over- and underapplication of the second coat are also detectable under UV. Throughout the life of the system, coating degradation can be easily and quickly monitored and captured digitally to record the system performance, allowing for easier repair.

The use of the OAA in a coating gives an indication of the DFT. It will highlight to an inspector areas of low and high DFT, making them much easier to spot from a distance. Under the UV lamp, most defect areas should be visible at a distance of at least 3 metres depending on ambient lighting conditions.

In general, a smooth uniform surface of equal luminous intensity (glow) should be achieved and is a sign of a good application. A non-uniform (patchy) appearance indicates a variety of possible defects, normally varying film build (see examples in Figure 6). The use of the OAA Figure 6: Typical defects found using OAA: (a) grey first coat showing through poorly applied second coat; (b) Poorly coalesced second coat; (c) microcracking; (d) wrinkling (first coat not fully dry)



does not eliminate the need for normal inspection processes but serves to readily identify areas of poor application, thus enabling a faster inspection process.

OAA and the IMO

The recent International Maritime Organisation resolution⁶ specifically states that while coating sea water ballast tanks (SWBT):

"Any defective areas, eg pin-holes, bubbles, voids, etc, shall be marked up and appropriate repairs effected. All such repairs shall be re-checked and documented."

While the resolution defines how to check and where to check DFT, there is no definition for determining the presence of pinholes, holidays, etc. Current practice would be to use low-voltage wet sponge testing techniques. However, at a rate of 10m² per minute as defined by NACE Standard RP0188–99,7 it is not practicable to use this method when examining the SWBTs of a very large cargo carrier (VLCC) which may have a total surface area in excess of 300,000 square metres. The much faster inspection rate available using OAA technology makes accurate inspection of this area of coating a practical and economic possibility.8

Practical benefits

In practical use, it has been shown that this system offers the following benefits:

- improved accuracy of inspection;
- reduced inspection time during application (up to 50% time savings);
- improved application resulting in a reduction in rework;
- reduction in the amount of paint used leading to lower VOC emissions;

- ease of recording defects for future comparison or remote off-site assessment;
- potential to improve the quality of the workmanship and hence future first-time quality of the application;
- detection of coating removal;
- ease of inspection of the coating by unskilled personnel;
- ease of determining early signs of coating failure during coating life.

Conclusions

Use of an optically-active coating system will ensure that the application process, both at new construction and during repair, is carried out defect-free with full coverage of all areas. As the coating system is defect-free, its overall quality will be improved and will ensure a longer period of maintenance-free service. If at first application there are no defects, re-work will be kept to a minimum.

This will reduce rework time and reduce paint usage. The reduction in paint usage will reduce VOC emissions from the site. Easier and improved inspections will allow for the identification of defects and repairs to the coating system at an early stage, preventing more expensive repairs as the damage increases through time. The use of optically-active additives is now well established, and SSPC have recently issued a technology update highlighting the technique.⁹

References



(FHWA), Office of Infrastructure Research and Development, Report FHWA-RD-01–156, September 2001

- 2. Biezma M V and J R San Cristobal, *Corrosion Engineering, Science and Technology*, **40**, (4), 344–52, December 2005
- Planck M, 'On the law of distribution of energy in the normal spectrum', *Annalen der Physik*, 4, 553, 1901
- Newton Harvey E, A History of Luminescence, (until 1900), Academic Press, New York 1996
- Department of Defense Single Stocking Point for Specifications and Standards (DoDSSP), Standardisation Document Order Desk, 700 Robbins Avenue, Bldg 4D, Philadelphia, PA 19111–5094
- 6. IMO Resolution MSC.215(82) adopted 8th December 2006, www.imo.org
- NACE Standard RP0188 (latest revision), Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Surfaces, Houston, NACE International
- Buckhurst and Bowry, 'An optically-active coating system for coating ballast tanks,' Paper T-44, presented at the Paint and Coatings Expo 2005, SSPC, Pittsburgh, 2005
- 9. Technology Update 11 Inspection of Fluorescent Coating Systems, SSPC, Pittsburgh October 2006