

## **PROGRESS IN OFFSHORE COATINGS**

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### **ABSTRACT**

This paper will cover the evolution of offshore systems over the past 20-25 years, starting with the use of zinc and vinyl or chlorinated rubber systems, and moving to the currently used high solids systems.

Consideration will be given to all the key regions of offshore production, including Gulf of Mexico, North Sea, Arabian Gulf and Asian fields, and how different construction processes, and arguably environmental conditions, drove a divergence of specifications which may now be converging again.

The strengths and weaknesses of various systems will be reviewed in terms of both New Construction and Maintenance.

Finally, the painting of Floating Production Facilities (e.g. FPSOs) will be considered, and how painting specifications for these have had to diverge from traditional approaches because of vastly different construction processes when compared to fixed platforms.

Key Words: Offshore systems; Zinc; FPSOs.

### **INTRODUCTION**

In the Offshore Coatings Industry, as with most things in life, it is easy to view the past through rose tinted spectacles. It is not unusual to hear a lament that there were no where near as many problems with systems applied 20-30 years ago and that such systems gave longer lifetimes.

This paper attempts to review where we have come from in terms of Offshore Coatings Systems, how this has evolved in various regions, why changes became necessary, and how these were addressed.

## HISTORY OF OFFSHORE COATINGS

It could be considered that the real growth in the Offshore Oil Industry coincided with the use of 'modern' high performance coatings, i.e. coatings not based on drying oils but rather synthetic chemicals such as vinyl resins and epoxies. These materials can have inherently better long term stability than alkyd or other oleo resinous materials as they do not cure by air oxidation, but rather are either physically drying or chemically crosslinking and hence do not suffer from long term embrittlement due to continuous crosslinking due to oxidation of unreacted double bonds.

At around the same time as this type of technology was evolving, surface preparation methods improved with the advent of sand blasting allowing removal of millscale, corrosion products and, at the same time, significantly increasing the surface area available to the coating for surface bonding.

Most of the early offshore platforms were situated in the Gulf of Mexico (GOM) and hence use the typical high performance coatings technology current in the USA at that time (1940's – 1950's), i.e. coatings were based on polyvinyl acetate copolymers and later on early epoxy amine systems (epoxy having been first patented and introduced in the late 1940's). The vinyl copolymer systems especially were low solids (20% volume solids), but due to relatively high molecular weight had good durability and long term stability. Special variants were used direct to steel where the presence of additional hydroxyl polar groups improved adhesion. In common with many chlorine containing systems, these coatings had excellent water resistance. Low solids meant that thick films could not be applied in a single coat, thus maximum dry film thickness per coat was around 50 microns (2 mils). The advantage of this was that with multiple coats pinholes and thin areas were not a problem. Also, because these coatings were based on solution polymers, there were no issues with Rothscoat adhesion even after ageing, the coating 'fusing' together on 'redissolving' to form a homogenous mass. Typically these were multi-coat systems, obviously relatively expensive to apply and could be between 5 and 7 coats, with total dry film thicknesses of 250-300 microns (10-12 mils).

Interestingly, vinyl, epoxy primers and chlorinated rubbers based on red lead were sold at this time and claimed to give excellent performance. This is likely to be doubtful as red lead functions specifically by reaction with linseed oil, for example, and is basically inert in other polymer systems. With oxidizing polymers such as alkyd, or preferably linseed oil, the basic red lead reacts with the carboxylic acid breakdown products to form lead soaps such as lead azelates. These are the actual inhibitors and function by thickening and repairing the naturally formed oxide layer on steel.

This has been demonstrated by formulating chlorinated rubber red lead primers plasticized with conventional chloroparaffins and linseed oil. The linseed oil based material gave significantly better performance. Unfortunately, the use of linseed oil in coatings gives other detrimental properties such as decrease in water resistance and resistance to saponification, which made its use unsuitable to the offshore environment.

An improvement to the system was to utilize zinc silicate as a primer, thus improving both underfilm corrosion creep and long term corrosion resistance.

This type of multi-coat thermoplastic resin based system, especially with inorganic zinc silicate as primer, was used for 30-40 years with considerable success and many platforms are still currently coated. It is worth noting that an alternative system using polyvinyl butyral/zinc tetroxy chromate wash primer direct to steel and then topcoated with the multi-coat vinyl system also gave excellent performance in the Gulf of Mexico.

Early vinyl coatings were not restricted by Health & Safety and Environmental requirements to what type of plasticizer was used, again contributing to long term stability to weathering, corrosion and thermal stress.

As time progressed and costs for multi-coat systems became more prohibitive, the tendency became to utilize low molecular weight vinyl resins in order to obtain high solids, higher build and less coats, and also to use blends of acrylic resin with the vinyl. These moves all contributed to reducing the overall effectiveness of the coatings.

What then were the defects or weaknesses of these materials?

- (i) Low solids - 20% initially, increasing to around 40% with vinyl/acrylics but clearly problems with VOC emissions.
- (ii) Thermal stability - thermal degradation (dehydro chlorination) becomes possible at temperatures greater than 80°C (176°F).
- (iii) Thermoplasticity - warm areas.
- (iv) Chlorine - chlorine containing polymers now have a problem with waste disposal where incomplete combustion can cause formation of extremely toxic dioxins.

Coatings of this type were successfully used by many companies in the Gulf of Mexico, e.g. Gulf, Philips, Exxon etc., and by Philips, Statoil and others in the North Sea.

Early epoxy systems were based on medium molecular weight epoxy resins, crosslinked initially with low molecular weight aliphatic amines. Thixotrope technology was not suitable for high build coatings so again multi-coat systems were used. The use of medium molecular weight epoxy in fact gave two major advantages, the molecular weight of around 1000 gave sufficient gaps between crosslinks to give some inherent flexibility, and hydroxyl groups present on the chain contributed to adhesion. Low solids also reduced solvent retention and consequent stresses induced via film shrinkage and again, as with vinyls, multi-coats contributed to overall performance. Typical coatings were around 40-45% volume solids and were applied at 50-75 microns (2-3 mils) dry film thickness per coat, with total thickness of 200-250 microns (8-10 mils).

Again, zinc silicates were also used as primers for these systems, improving underfilm creep and overall corrosion resistance.

In underwater and splashzone areas, the most common system was multi-coats of coal tar epoxy, typically 300-500 microns (12-20 mils) dry film thickness. In early times, with pure vinyls, it was also possible to use these in this area.

## **REGIONAL VARIATIONS**

The start of the North Sea Offshore Industry in the late 1960's brought a whole series of new problems compared to those in the Gulf of Mexico:-

- aggressive exposure environment due to high and continual wave action, salt spray and almost continuous wetness;
- higher wave action;
- sea salt splashing;
- application under low temperature conditions, typically down to 5°C (40°F) during day time application with sub-zero cure overnight;
- larger structures;

- different fabrication procedures. In the U.S.A. structures typically being primed with zinc silicate then allowed to weather before topcoating. In the North Sea a “black box” procedure was adopted, especially for accommodation and process modules where the structure was completely erected in ‘black’ steel (millscale) then blasted and primed as part of a single process;
- inexperience with zinc silicates.
- Introduction of chlorinated rubbers as alternative thermoplastics to vinyls.

The aggregation of all of these issues contributed to a number of difficulties and short lifetimes to first maintenance on a number of early structures, but by the late 1970’s this had largely been resolved. Zinc silicates could now be used but in many instances were replaced by zinc rich epoxies, fabrication processes had been refined and coatings formulated suitable for temperate climate application. There were still a number of anomalies, for example, the use of chlorinated rubbers or vinyls as the topcoat for an epoxy system – to aid aged overcoating at maintenance and improve weatherability. This produced many ‘strange’ epoxies formulated in an attempt to achieve good adhesion thermoplastic finishes.

Chlorinated rubber coatings suffered of the same defects mentioned earlier for the vinyl materials, with a greater problem in thermoplasticity, thermal degradation and weatherability, but also being susceptible to contamination by oil/grease etc. Eventually these chlorinated rubber topcoats were overcoated with special surface tolerant epoxies, thus allowing an improvement in oil resistance.

In underwater and splashzone areas thick epoxy cladding systems became popular, typically 3000-6000 microns (120-240 mils) dry film thickness, these were applied either in multi-coats by standard airless spray in a single coat by specialized equipment.

Thus by the late 1970’s in the GOM systems started to become the precursors of those used today, followed by the Persian Gulf, and the North Sea, i.e. a system comprising zinc rich, high build epoxy, polyurethane.

The basis of this type of system remained that of many years but thixotrope technology allowed the use of high build epoxy coatings, reducing the overall number of coats, and the evolution of a hydroxy acrylic based polyurethane as distinct from the densely crosslinked polyester type allowed a recoatable durable finish to be used for the first time.

In some ways this reduction in the number of coats and application of thick films started to show some of the problems which are sometimes now observed, i.e. film instability on ageing, leading to cracking, especially in poorly prepared and thick areas such as welds.

When this type of system was formulated and applied correctly excellent results could be achieved, despite this all the inherent difficulties of using zinc silicate primers remained, i.e. potential poor cure at low humidities and subsequent splitting and pinholing difficulties on overcoating. However, due to adverse weather conditions, abuse of products at application, or non-compliance with data sheets, major problems could occur which never happened with the single pack solution polymer thermoplastics where adhesion was never a problem.

The use of zinc rich organic primers (specifically epoxy) was a major difference between the North Sea and the Gulf of Mexico. This was largely driven by the easier use of zinc epoxy – no humidity restrictions (often in Northern Europe relative humidity can be low, especially in painting halls in winter time it can be 20%), thus production schedules could be more easily met and overcoating times guaranteed. Also, the use of a tie coat or mist coat was not necessary.

There has been continual debate over the years as to the effectiveness of zinc rich epoxies when compared to zinc rich silicates. Certainly as single coats, the inorganic zinc silicate will always out perform a similar zinc level (by weight) zinc epoxy (largely due to the higher level of zinc dust by volume in the silicate film due to the higher density of the silicate matrix when compared to the cured epoxy polymer).

However, when topcoated, extensive accelerated testing and external exposure testing have shown that there is little difference in performance, either in terms of corrosion creep from damaged areas or general areas between a well formulated zinc rich epoxy and an inorganic zinc silicate.<sup>1, 2 & 3.</sup>

In the 1990's twin pressures had driven a move to higher solids coating systems, i.e.

- reduction of solvent emissions (VOC);
- reduction of number of coats – cost.

A consequence of this was to move to thicker films per coat, both intentionally and because of higher solids being used.

There was also an unfortunate philosophy within the industry, possibly propagated by paint manufacturers in a desire to sell more paint, that thick films are good and the thicker the better. This led to an increasing use of both thick intermediates and thick barrier coat primers.

This proposition does not live up to examination. Laboratory corrosion testing can relatively easily demonstrate that with very thick films corrosion from a holiday may appear to be very small but on examination is major – the thick films preventing blistering and making it less obvious that there is under film corrosion.

In practice it is difficult to apply even films due to both statistical spread of dry film thicknesses on a flat area, and even more so the difficulty of applying even films on complex areas. Stripe coating procedures, which are widely used within the industry, can further increase film thicknesses.

## **EFFECT OF PAINTING PROCESS**

Offshore maintenance programs are becoming increasingly expensive and complex, clearly painting tends to fall behind many other activities in terms of priorities, but many of the old philosophies are no longer possible.

- In many areas of the world dry blasting offshore is no longer allowed, replacement by UHP water blasting is now doubtful following considerable offshore experience in the North Sea because of Health & Safety considerations, i.e. dangers of the high pressure jet and the logistical difficulties of operating this heavy equipment continuously.
- Logistics of moving painting areas around can be considered high risk and potentially unacceptable in risk assessment processes.

This all puts further emphasis on 'good' new construction systems being used, which can offer maintenance free lifetimes of many years (>20 years). Prequalification testing, which is covered in another paper, is the most used route to try to achieve this.

A further degree of complexity has now been introduced into the painting process. Traditionally, offshore structures were constructed by fabricating the structure, be it a jacket, deck or module, then blasting and painting. This process could, in many ways, be considered one of the best options open, all welds should be blasted, overcoating qstol should not be exceeded, and minimum contamination between coats. Optimal zinc rich primers could easily be used in the process.

The advent of deep water production has caused changes. Structures of the above design are not suitable here and floating production and storage units have been developed as alternatives (FPSOs and FSOs). These are basically very large barges or super tankers without engines, oil is stored in tanks and regularly removed by shuttle tankers. In configuration terms, cargo tanks/water ballast spaces, they are similar to super tankers and, consequently, tend to be built in shipyards rather than traditional offshore construction yards. In one major respect they are different to tankers in that having been put on station they are basically expected to operate for the life of the field (20, 30 or more years) without any dry-docking. When the vessel is moved from the field it must be towed and disconnected from all the connecting underwater infra-structure producing the oil, i.e. no production if vessel moved.

With early FPSOs, the procedure tended to be that the hull would be built in a shipyard and the process and accommodation modules in traditional offshore yards. Now everything is often built in an offshore section of a large shipyard.

For the hull section, early specifications tended to follow traditional systems used for jackets with, for example, thick glass flake system in the splashzone area and potentially non-specialized coatings in the water ballast and cargo tanks. What this ignored was the building process which has evolved in most major shipbuilding yards. Here production is via a "block" process where sections of the hull structure, typically 200-500 tonnes in weight, are fabricated in steel, coated with prefabrication primer, welds fully blasted, the remainder sweep blasted, and then the full system applied. These blocks are then welded together to form the full structure. In most cases, practicalities prevent full blasting of the join-up welds and these tend to be ground and power disced.

This whole process of block fabrication is now also being used for the deck modules, rather than fully fabricating then painting. Offshore fabricators using this process work very much on a production line basis, each coated block must be in the right place, at the right time, and there can be no hold ups, a number of vessels are in the dry-dock at any one time and progress on all of these must be synchronized to allow flooding.

In many cases, to ensure production schedules are met, coating application is directed at being absolutely certain that required dry film thicknesses are met, even at the risk of over-application and over usage of paint. This, together with the use of stripe coats on welds/edges etc., can lead to extremely thick areas up to 3-4 times specified dry film thickness. These extreme conditions, with film thicknesses of up to 1.5mm, have led to cracking with a number of coatings (and are the reason for the over-thickness cracking test in NACE TG263 for water ballast coatings).

Emphasis has been to have coatings which fit with production process re all weather, fast cure, rapid handling, overcoating and over-thickness tolerance, rather than performance orientated, without great concern for application properties as has been the case for traditional offshore systems.

The joint effect of prequalification testing and increasing structures being built in this way means that neither property (i.e. performance or application) can be ignored, both have to be built into the product design and achieved in the final formulation.

## **NEW TECHNOLOGIES**

Offshore corrosion protection is critical, and hence over the years operators have been willing to try many 'new' or 'novel' coating systems, often with little track record or test data, in the hope that these would solve corrosion problems. Included in the many technologies that have been tried are thick film urethane elastomers, oil displacing modified epoxies, flexibilized epoxy phenolics, zinc coated blasting media, thermally sprayed copper antifouling, moisture cured urethanes.

Most of these approaches have now been abandoned, the systems did not go through the current type of prequalification testing and, in many cases, it is doubtful if they would succeed if they did go through the test.

It is likely that new technologies going forward will be based on more reasoned and studied chemistry, patenting will become more of an issue in the industry (with obvious implications to users), and there are decision making tools starting to become available to help make performance and suitability decisions.

A good example of new technology for offshore is the use of inorganic hybrid materials (polysiloxanes) as super durable finishes. These are based on new chemistry and have required extensive laboratory work to understand the implications of the competing crosslinking reactions. Initially it could be argued that the technology may have been oversold in terms of inherent anti-corrosive properties, but this was probably also tied up with long term offshore anti-corrosive systems only consisting of two relatively thin coats requiring non-standard application procedures to ensure correct dry film thickness.

Much more consideration is now being given to modes of failure and coatings formulated to alleviate these weaknesses. A good example is edge breakdown, inspection generally shows this area to show first failure. New formulations are being developed which give better wrap round properties, even with airless spray application, and actual edge coverage is now being regularly measured. Examples are shown in Figures 1 – 6.

Other areas where new coatings are being continuously improved is to resist cracking on the inevitable over-thick areas, which often occur on poorly prepared areas such as welds.

Thus new technology can be considered to move in two directions:-

- (i) To improve application efficiency and tolerance, possibly of existing basic technologies.
- (ii) To develop new inherently more stable and durable chemistries, which meet all application requirements and give longer lifetimes.

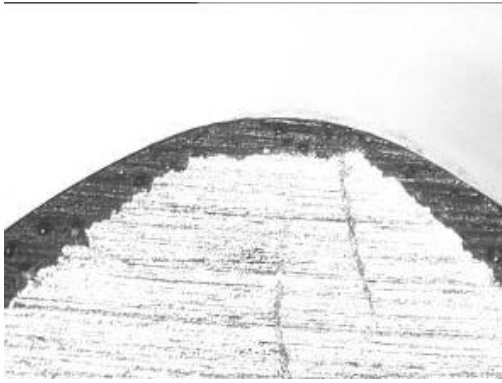
### **Summary**

Offshore coatings have evolved considerably since the early days of offshore oil production, however, in terms of overall performance it may be questionable as to whether this has significantly improved given that it is difficult to substantiate reports from the field on conventional zinc silicate/low solids systems compared to current materials. Application processes have become quicker and more environmentally tolerant, coatings themselves require fewer coats and meet more environmental and health and safety needs, but if longer lifetimes are not being achieved these benefits are questionable.

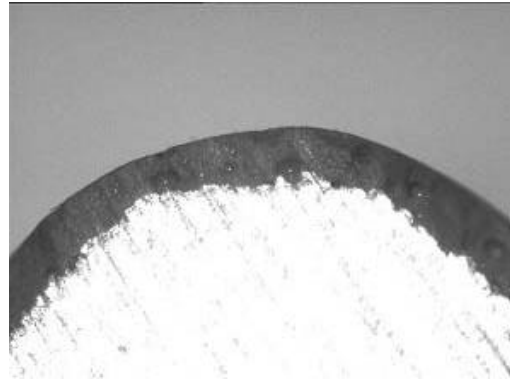
However, all is not black, the introduction of more realistic testing scenarios, new chemistries such as polysiloxanes, and a recognition by all parties involved in the painting process, should start to give prequalification benefits over the next few years.

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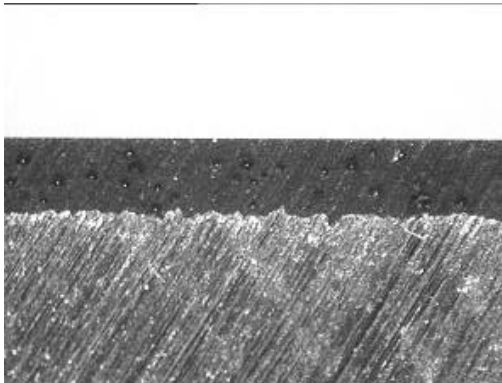
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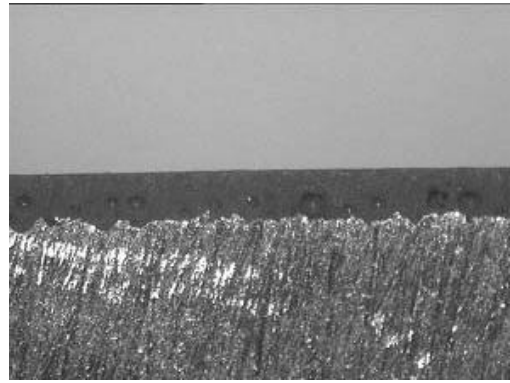
**FIGURE 1 – Epoxy polysiloxane (1.2mm edge)  
(40% edge coverage)**



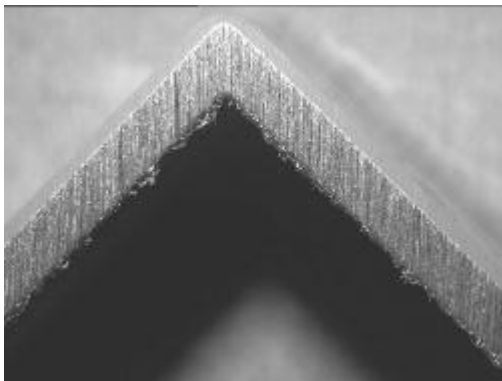
**FIGURE 2 – Urethane acrylate polysiloxane  
(1.2mm edge) (70% edge coverage)**



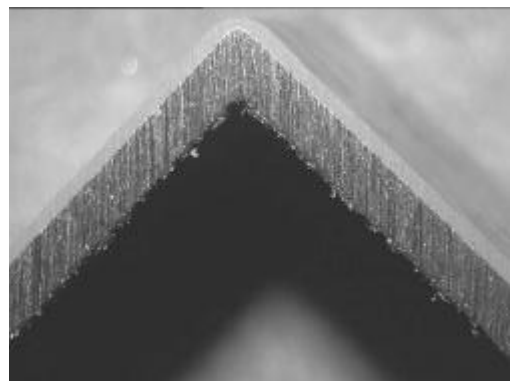
**FIGURE 3 – Epoxy polysiloxane – flat area**



**FIGURE 4 – Urethane acrylate polysiloxane –  
flat area**



**FIGURE 5 – High solids epoxy mastic  
(70% edge coverage) (Sample 1)**



**FIGURE 6 – High solids epoxy mastic  
(70% edge coverage) (Sample 2)**