Materials of Construction in a Solar Salt Environment

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Abstract

Evaporative solar salt mines, such as those owned by Rio Tinto's Dampier Salt Limited (DSL) operations, involve the intake and progressive evaporation of seawater, continuing until salt is cleaned, dried and exported for various chemical and culinary uses. The combination of high ambient temperatures, constant solar exposure and salty water cause significant degradation of fixed plant assets at such mines in the form of corrosion and material build-up. This investigation serves to expose a variety of metals, plastics and composite coatings to degradative environments through laboratory simulations, and additional on-site testing. Experimentation is to provide DSL personnel with knowledge of chosen materials' performance in regards to build-up and corrosion characteristics, with consideration for cost, cleaning and maintenance requirements. These works have shown desired outcomes for plastics such as polyvinyl chloride (PVC), displaying minimal build-up and no corrosion, with limitations arising due to their water absorption properties. Although requiring significant capital expenditure and application provisions, epoxy barrier coatings will provide metallic assets with superior protection in solar salt environments.

1. Introduction

Dampier Salt Limited (DSL), owned predominantly by Rio Tinto, produces and exports seaborne salt with a capacity of 10.3 million tonnes per annum over three operations: Dampier, Lake MacLeod and Port Hedland. At DSL's sites, process issues arise due to the hot, humid and extreme Pilbara environment, combined with the harsh and destructive impact of salty water on materials of construction. As a result, components such as pumps, piping and gates are experiencing loss of efficiency and in several cases, catastrophic failure, leading to increased downtimes and costly material replacements.

The objectives of this project involve recommendations of materials and coatings to DSL to reduce the effect of three main issues: salt build-up, gypsum build-up and corrosion. Recommendations are to influence reviews of DSL material specifications and therefore, future planning, procurement and construction.

1.1 Background

DSL's sites suffer extensive material deterioration, partly due to age of components, however, these issues can be attributed to the harsh Pilbara/Gascoyne environment combined with the destructive nature of sea salt – especially on metallic materials.

1.1.1 Corrosion

In general, pitting corrosion is the most common form of corrosive damage when metals are subjected to oxygenated seawater. Pitting occurs as a local attack in areas where protective passive films and/or coatings have been damaged, usually at areas of imperfections, forming small cavities or 'pits' (Bhandari et. al., 2015). In marine environments, pitting is the greatest threat to steels, including stainless steel, commonly thought to be corrosion resistant (Bhandari et. al., 2015). Pitting corrosion, in the context of DSL's environment can lead to:

- Localised structural member overstress
- Leaking and unlicensed discharge from pipelines and culverts
- Mechanical component breakdown / failure
- Primary structural failure (in extreme cases)

Occurring in a similar mechanism to pitting, crevice corrosion can be an issue for DSL's assets if not properly managed. Pitting occurs at locations of vulnerability or defect, whilst crevice corrosion usually begins at areas of improper design or small tolerances such as welds or fittings, and typically initiates more aggressively than pitting due to faster electromigration of ions and the lower critical potential (Szklarska-Smialowska, 2005).

1.1.2 Gypsum Buildup

Gypsum is the world's most common sulphate mineral, known to precipitate from evaporated seawater such as the brines used in DSL's crystallisation process (Reiss et. al., 2021). Gypsum crystallisation occurs due to nucleation, in which the solute, calcium sulphate, gathers into clusters within the solvent (water), stabilises and does not dissolve. Nucleation and simultaneous growth of these clusters occur due to the solution becoming supersaturated as the water evaporates – that is when the concentration of solute exceeds equilibrium solubility. Gypsum buildup at DSL continues to cause blockages in process piping and breakdown of pumps, both causing a reduction in crystallizer pond filling rates, typically at locations of higher brine concentrations, further along process.

1.1.3 Salt Buildup

Highly concentrated saline water, such as that found in crystallisation ponds at DSL sites, can promote significant build-up of unwanted materials, known as scaling. These materials can include carbonates, silicates and hydroxides. Build-up may cause overworking of mechanical components such as the 6" pumps, and can lead to restriction of flow, resulting in downtimes and repeated and difficult cleaning. As with gypsum buildup, salt deposits in process piping and on pumps inhibit process flow capacity and increase risk of sub-par production outputs.

2. Process

2.1 Screening Experiment

Due to the quantity of materials to be tested, an initial screening experiment was conducted on UWA premises to screen out poor-performing specimens. The experiment was conducted in a bucket filled with seawater, with all specimens placed into this pool, heated at a constant rate until the seawater evaporated to a level below the coupons as per the schematic in Figure 1. Specimens were photographed and weighed before and after the process, and qualitative and quantitative observations are subsequently made. The best performing coupons, based on relevant criteria were advanced to on-site testing.

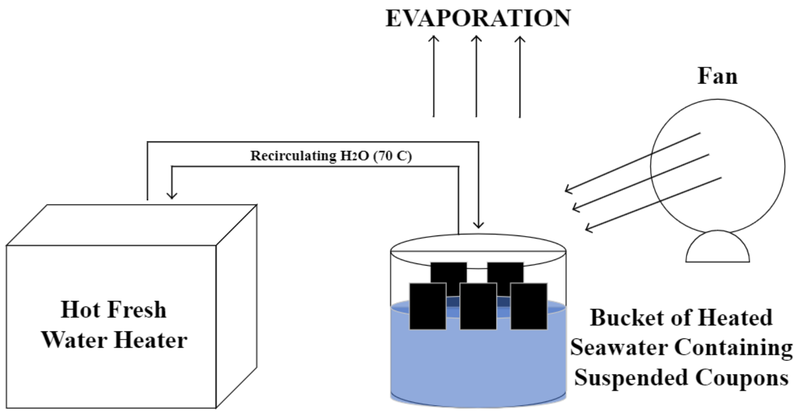

Figure 1 Schematic of Screening Test Rig

2.1.1 Scoring Criteria

Further to the response of tested coupons to degradative processes such as corrosion and build-up, application of these materials on-site will require differing levels of financial investment as well as operator care, which are considered in the comparison. Therefore, the 'scorecard' for each material is based on build-up characteristics, ease of cleaning, corrosion characteristics, cost and ease/requirements for maintenance, each on a scale from 1 to 5 (5 being desirable).

Material scores resulting from screening experimentation are therefore a sum out of 25, in which higher scoring materials are considered for on-site experimentation.

2.2 On-Site Experiment

The experimental test method will be a simple coupon test. Following the screening test, coupons are to be placed in different areas of the DSL Process for a period of around three to four months:

- Seawater Inlet
- Crystalliser Pond Inlet
- Wash Plant

Observations of colour changes, build-up, corrosion, material feel are to be taken and documented. These observations are to be paired with quantifiable measures i.e. weight gain due to build-up, weight loss due to corrosion. The same scoring method will be used to rate the specimens as in the screening test.

3. Results and Discussion

3.1 Screening Experiment

3.1.1. Build-up

Coupons were weighed and recorded after every cycle. The total weight gain after 10 cycles is shown in Figure 2, with values standardized per square metre.

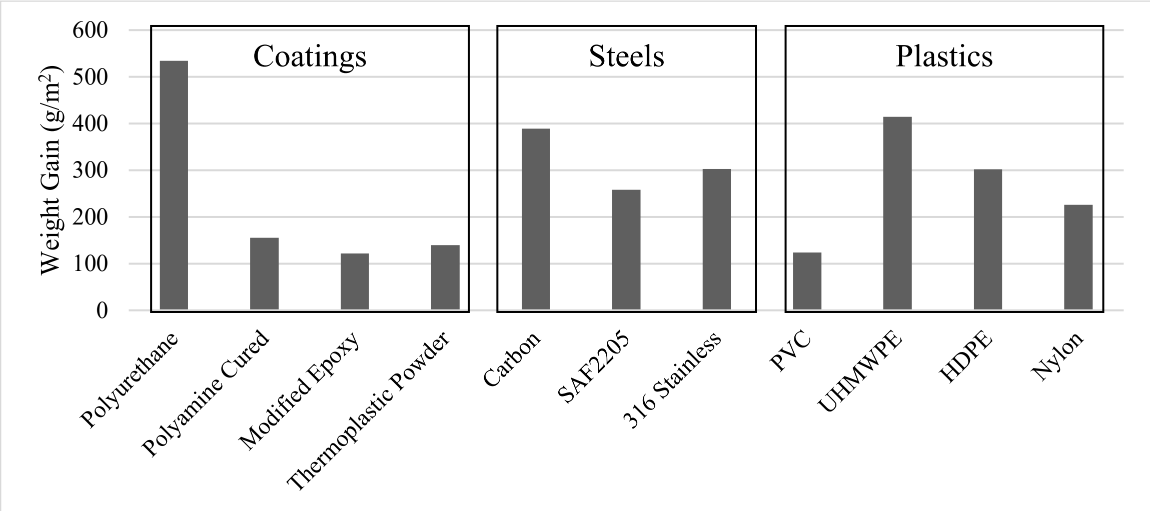

Figure 2 Screening Test Weight Gain per Surface Area

These values are also paired with visual inspection, as weight gain may also be attributed to water absorption, which is an issue associated with plastics such as HDPE, experienced on-site. PVC and the thermoplastic powder coating gained 124 and 139 g/m^2, respectively, combined with minor appearance changes and were hence given 4/5.

3.1.2. Cleaning

As per the scoring mechanism, after screening, samples underwent a cleaning procedure. Firstly, each coupon was subject to light tapping with a pen, which saw some salt become dislodged, however, each sample still contained salt adhered to their surface. Secondly, the samples were placed under light running tap water for 15 seconds. During this event, the four plastic samples were instantly cleaned to appear as new, with polyurethane and adhesive thermoplastic coating displaying similar behaviours. The remaining materials still possessed salt crystals on their surface and required further water stream exposure. Carbon steel continued to display rust build-up, and required some light scrubbing to remove this.

3.1.3. Corrosion

Carbon steel was the only material to undergo corrosion throughout the screening experimentation. Rust formed after only three cycles, and the rusted surface was able to be scraped off. The location of rust build-up likely caused ridges for salt build-up to occur and hence, did not lose weight as a corrosion test would likely indicate. Both 316 Stainless and SAF2205 duplex steels did not show any pitting or indication of rust. Therefore, all materials received a 5/5 score for corrosion, whilst carbon steel received 1/5.

3.1.4 Cost

Cost is a significant factor in the proposed materials' viability to be introduced on site. Through market research it was concluded that carbon steel, and the three plastics were below \$100 /m^2 and therefore given a 5/5 rating. Nylon liner was quoted to within range of \$300 – \$400 /m^2, and therefore given 2/5 for cost. As per email correspondence with vendors, the thermoplastic coating was quoted at \$160 /m^2, whilst the two epoxy coatings were below \$100 /m^2. These coatings are typically applied on steel surfaces, and therefore as an estimate, coating costs were increased by \$50 /m^2.

3.1.5 Maintenance

Maintenance analysis involves consideration of expected life, availability of maintainers (where applicable) to access DSL sites and conduct relevant works, and the cost of maintenance works. Via datasheets, the expected life of the coatings are beyond the required 30 years; however, coating works will require relevant shutdowns of site, as well as intricate surface preparation. Polyamine cured epoxy requires minimal surface preparation and only a single coat, hence, achieved a 4/5 rating, whilst modified epoxy may require thicker, multiple layer coating in the aggressive environment. Coating vendors have offices in Perth, and DSL has local contractors to repair and maintain the products.

Plastic materials are not expected to be as durable as steels in a solar salt environment. Likewise, steels are desirable in comparison to plastics in terms of hardness and therefore can be expected to undergo less frequent maintenance on-site. Plastics will have expansion issues and therefore may require more frequent changeout than metallic materials. Metals require constant provision for corrosion, and in the event of damage, will require boilermakers or similar to conduct works. Nylon maintenance score is lower than that of the other plastics due to the need to adhere the liner to another surface, therefore creating more effort in installation and maintenance.

3.1.6 Final Scores – Screening

As seen in Figure 3, the most desirable materials, based on the scoring mechanism proposed by these works, are PVC and modified polyamine cured coating, scoring 21/25, due to low-cost procurement, minimal build-up and ease of cleaning. Modified epoxy barrier (20/25) and thermoplastic powder coatings (20/25) both display strong performance in these harsh environments. Likewise, 316 stainless and SAF2205 were consistent in terms of their material performance, and hence, taken forward for on-site testing.

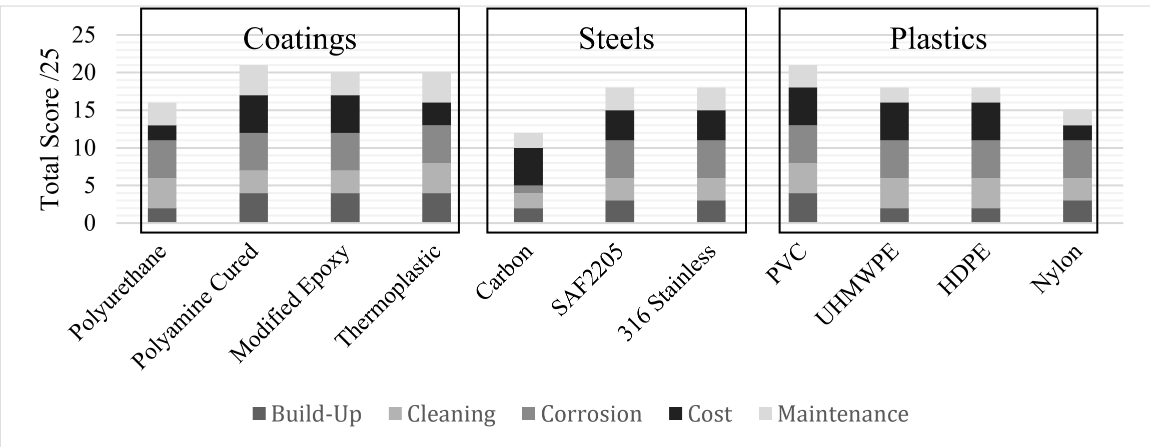

Figure 3 Screening Test Material Scores

3.2 On-Site Testing

Minimal impact is expected for the on-site samples over the short period of time (three months). Of note, from initial on-site observations and measurements, both 316 stainless and SSAF2205 duplex steels at the seawater inlet displayed feint red spotting, which can be attributed to the commencement of pitting. At the crystallizer inlet, build-up of dirt and sand was noted, which is not relevant to the current investigation, however may provide insight into adhesion / roughness characteristics of each material. As expected, salt build-up was noticeable at the wash plant inlet, likely due to higher density flow, with 316 stainless steel and SSAF2205 displaying the highest salt build-up of 2.45 g and 2.52 g, respectively.

4. Conclusions and Future Work

Screening tests allowed for rapid simulation of DSL's processes, with observations made regarding build-up and corrosion behaviours of selected materials. Of note, epoxy coatings displayed minimal salt build-up throughout the process and no corrosive impact to the carbon steel they encapsulate. Although likely to incur considerable costs, these are recommended for use key assets such as those within the wash plant. PVC performed similarly to the coated materials, and due to its' low cost, can be rolled out throughout the three sites, possibly for pipework and gates, however, provisions are to be made for thermal expansion and strength.

On-site works are ongoing, with final measurements and observations to be taken in late September. Build-up is expected to be minimal over this short period of time, and testing should realistically be considered beyond the scope of this project over several months / years. DSL are additionally recommended to conduct similar experiments on future proposed materials as the 'screening' test conducted in these works can provide indication of material performance within a solar salt environment conveniently within a matter of days.

5. Acknowledgements

The DSL on-site team at Port Hedland has been incredibly welcoming and supportive throughout my site visits, and I am incredibly grateful for their support. Thanks especially to Sam Cherian, Martin Groen and Pav Petrov. Furthermore, this project could not have advanced without the behind-the-scenes work of Jemma Ehsman, Vanessa Farquharson and Beezan Rind.

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