

High Performance Coatings



Agenda

- Situational Assessment
- Organic Coating Technology
- Comparison of Different technologies
- Latest Developments
 - Rapid recoat epoxies
 - Chemical resistant linings
 - Polysiloxanes
 - High Heat/ CUI
- Summary



Situational Assessment

- There is an improvement in the general awareness in terms of need of corrosion protection.
- Newer Technologies are getting used, products like Zinc silicate becoming fairly common.
- Significant % of users still *do not paint because 'want to'..... but because 'have to'*.
- While the technology in products have moved significantly, the application has not been able to keep up pace with it.
- Scope of improvement in local standards, standardization
- Need to move forwards on HSE and VOCs

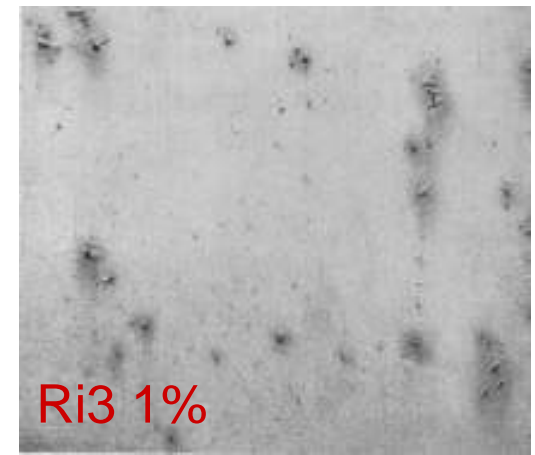
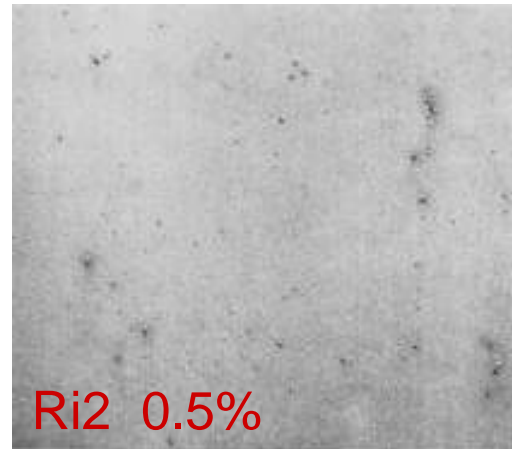
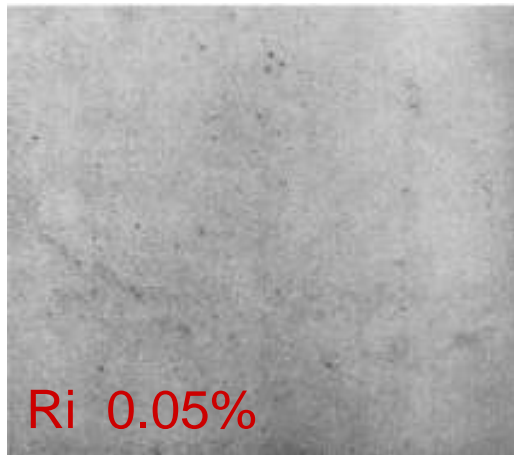


Classification of Environment ISO 12944

Class	Degree of Corrosivity	Exterior	Interior
C1, C2	Very Low, Low	Rural Areas, Low Pollution, Dry	Buildings, Neutral atmospheres,
C3	Medium	Urban and industrial atmospheres, moderate So ₂ , Moderate coastal	Production rooms with high humidity and air pollution
C4	High	Industrial and coastal	Chemical Processing Plants
C5-I	Very High Industrial	Industrial with high humidity and aggressive atmosphere	
C5 M	Very High Marine	Marine coastal, offshore, High Salinity	

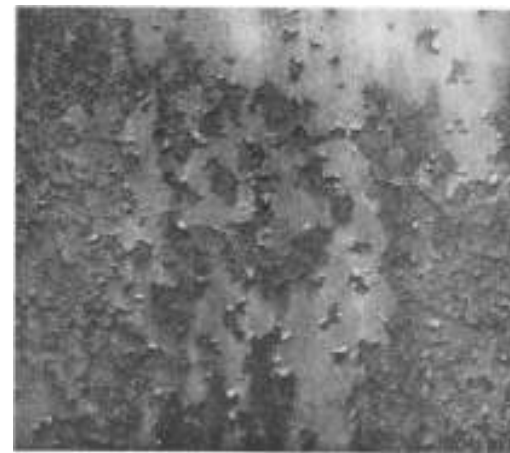
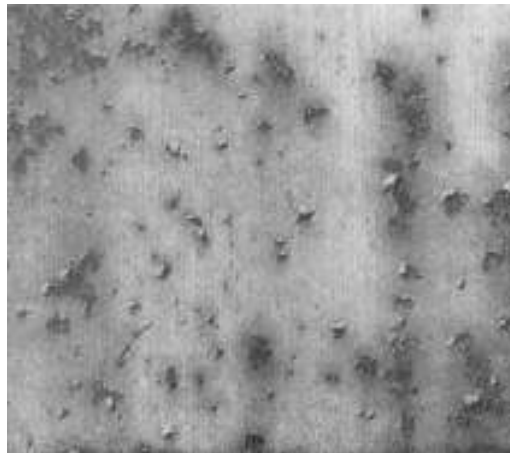


Extent of Defects – ISO4628



ISO 4628-3-1982 Designation of degree of rusting

Ri4 8%



Ri5 40 – 50%



Standards and Specifications

- ISO 12944
 - ISO 20340
 - NORSOK M 501
-
- NACE Standards/ Test Methods,
 - SSPC Standards/ Test Methods
 - ASTM Standards/ Test Methods
 - ISO Standards/Test Methods



Technology Requirements

- M&R Coatings need to be formulated to cope with the following requirements :-
 - Degree and type of surface preparation process utilised
 - Dry Blasting - Not always possible
 - Hydroblasting / Wet Blasting - Not always possible
 - Power tool / Hand tool
 - SSPC SP11 – Preferred as it provides a surface profile.
 - St2/3 (SSPC SP2/3) for surface tolerant coatings
 - Flexibility in application method Spray, brush, roller
 - Overlap with existing / aged coatings.
 - Environmentally compliant – Lower VOC
 - Customer performance expectations – Life Cycle



How do Coatings Protect Steel Structures?

- Coatings protect steel by either one or combination of the following mechanism:-

- ê Barrier Protection

- ê Inhibition of the steel surface

- ê Cathodic Protection



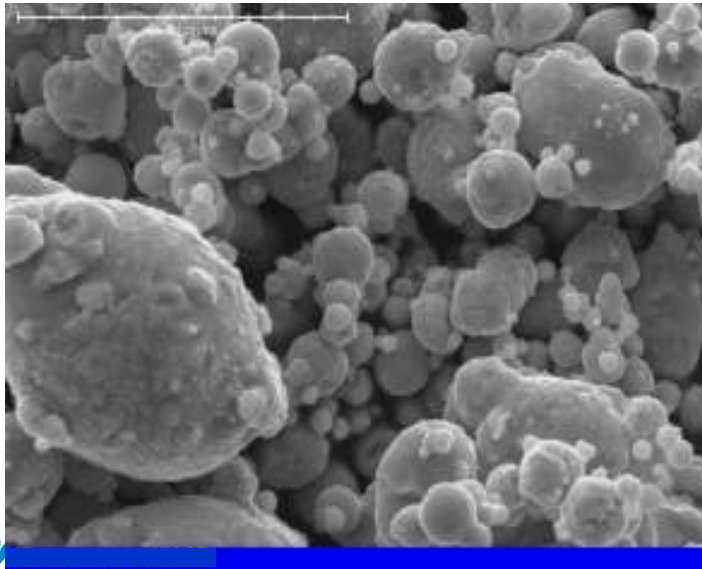
Cathodic protection

Anti-corrosive:

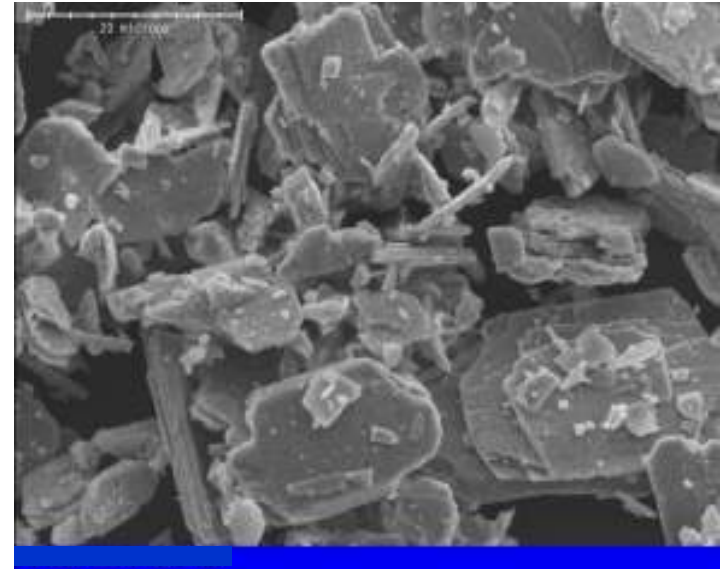
To prevent corrosion of metals by chemical and electrochemical means.

Examples are:

Zinc Dust



Zinc Phosphate



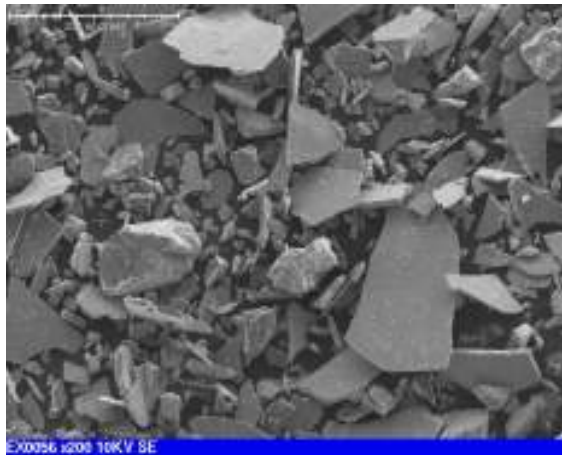
Cathodic Protection

Barrier:

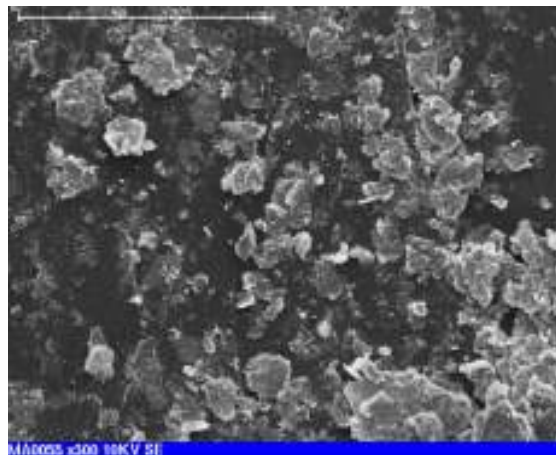
To increase the impermeability of the paint film to water, oxygen and ions.

Examples are:

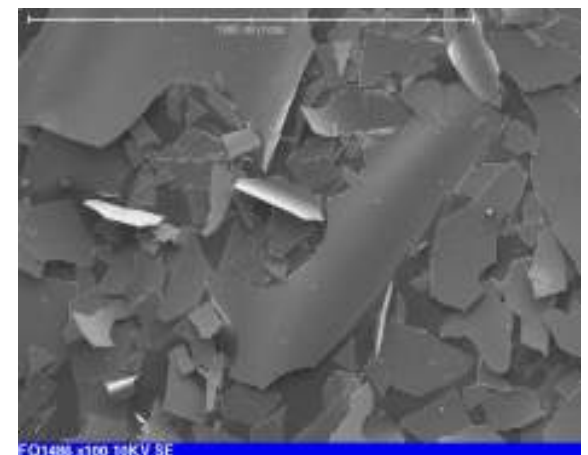
MIO



Aluminium



Glass Flake



High Performance Coating Systems

Systems:

- Alkyds and Modified Alkyd based paints
- Chlorinated Rubber/ Vinyl / Acrylic resin based paints
- Polyurethanes
 - > Silicones
 - > Silicates
 - > HR products
 - > Epoxy/ Epoxy Modifications
- Zinc Rich Silicate Based Coatings
 - > Polyester/Glass Flake based Coatings
 - > Polyurethane Based Coatings
 - > Polysiloxane Based Coatings
 - > Solvent less Coatings



High Performance Coating Systems: Comparison

Paint Type	Mechanical Properties	Cosmetic Properties	Over Coatability	Resistance to			
				Water	Acid	Alkali	Solvent
Acrylic	Moderate	Very Good	Good	Moderate	Good	Good	Poor
Chlorinated Rubber	Moderate	Moderate	Very Good	Good	Good	Good	Poor
Bituminous	Poor	N/A	Very Good	Very Good	Good	Good	Very Poor
Vinyl	Good	Good	Very Good	Good	Good	Good	Moderate



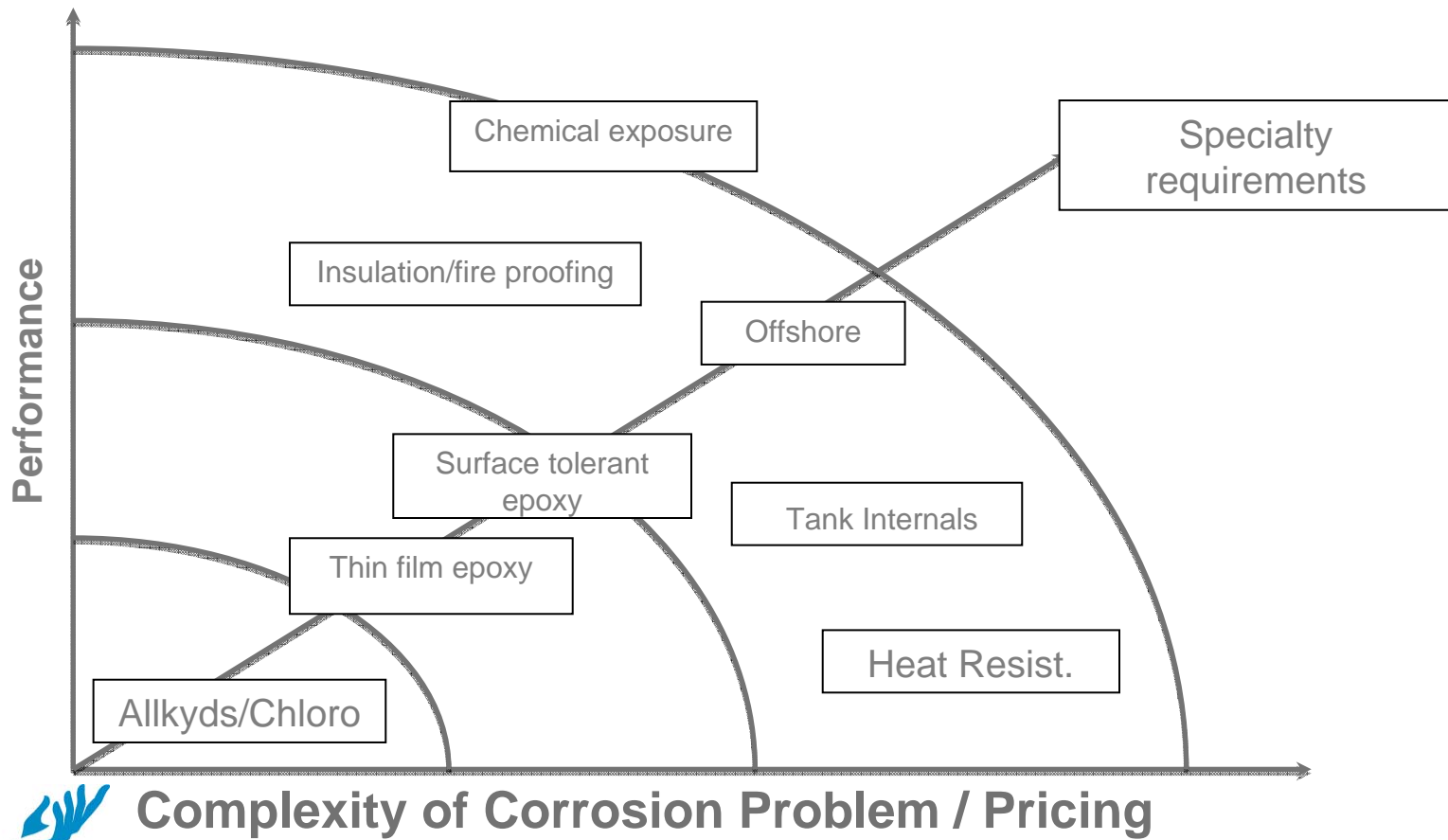
High Performance Coatings Systems

Convertible Coatings General Properties:

Paint Type	Mechanical Properties	Cosmetic Properties	Overcoatability	Resistance to		
				Acid	Alkali	Solvent
Alkyd	Moderate	Good	Good	Poor	Poor	Moderate
Epoxy	Very Good	Poor	Poor	Very Good	Very Good	Very Good
Epoxy Phenolic	Very Good	N/A	Poor	Excellent	Excellent	Excellent
Polyurethane	Very Good	Very Good	Moderate	Very Good	Very Good	Very Good
Zinc Silicate	Very Good	N/A	Mixed	Very Poor	Very Poor	Excellent



High Performance Coating



Maintenance Considerations

Degradation caused by corrosion represents a significant challenge to maintenance personnel as considerations must be given to:

- Corrosion Under Insulation (CUI)
- High Heat Corrosion
- Corrosion Under Fire Protection (CUF)
- Chemical Corrosion
- General Atmospheric Corrosion Issues
- Structural Safety Integrity Issues



Discussions on Technologies

Alkyds

- Good for low corrosivity areas Primer and finishes. (C1/C2 – ISO12944)
- Red oxide based materials (Primers) are most ‘inert’ material, but not true ‘anticorrosive’ – neither provide cathodic protection, nor inhibitive mechanism
- Lead and Chrome pigments are banned in most parts, of world due to HSE issue
- Surface preparation requirements both in New construction and maintenance.
- Applied brush. Roller, spray



Alkyds

- Surface tolerant to a large extent, but issues with building high DFT, auto-oxidative polymerization being an issue with thick layer of polymer.
- DFT per coat - low.
- Provides moderate durability, very good aesthetics
- Poor Chemical, resistance
- Breakdown very fast once corrosion starts



Chlorinated Rubber

- Not used in most parts of the world, alternate promoted single pack Acrylics with similar performance
- Good resistance to Chemicals
- Poor Solvent and Temperature resistance
- Building high film thickness may be issue in many cases.
- Potential problem of crazing & Cracking due to plasticizer evaporation.
- As a matter of Fact, most of the products supplied in the form of modified chlorinated rubber paints either have significant of traditional alkyds/ hydrocarbon resins or Chlorinated paraffin wax derivatives.

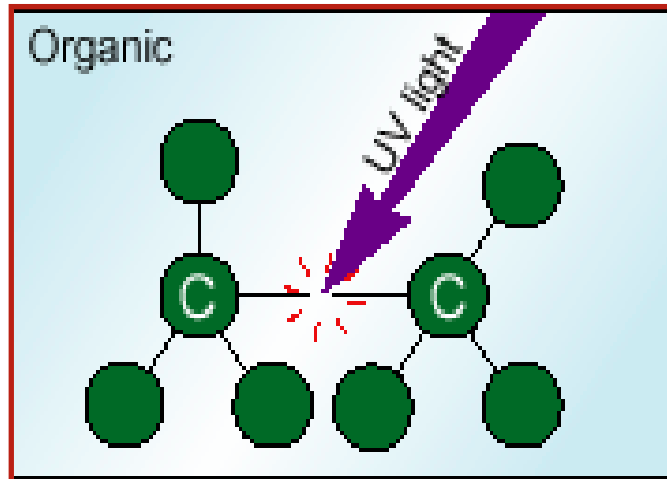


Acrylics

- Single Pack Acrylics – Alternate to Chlorinated Rubber
- Very good UV Resistance => good colour retention and gloss retention.
- Low DFT build up per coat
- Poor Chemical resistance to temperature and solvents
- Two pack systems with Isocyanates = > Acrylic PU coating provide excellent durability
- When combined with Polysiloxane, provide exceptionally good durability

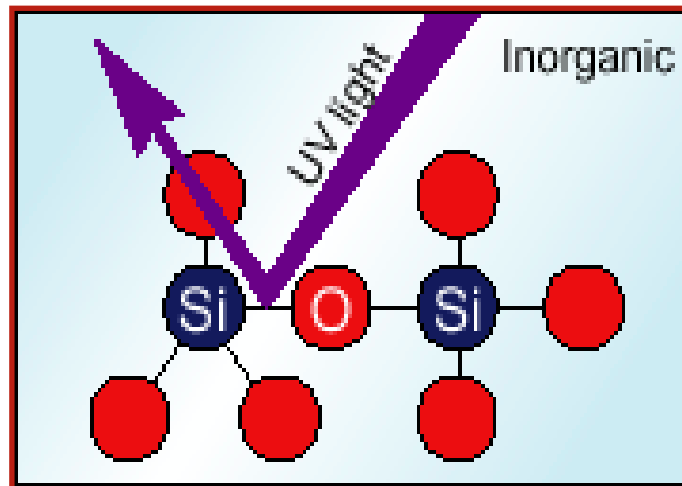


Technology - Inorganic Backbone – Polysiloxane



The Carbon-Carbon (C-C) bonds within traditional “organic” coatings are less resilient than those found in acrylic polysiloxanes

*The energy required to break a C-C bond is
350 kJ/mol*



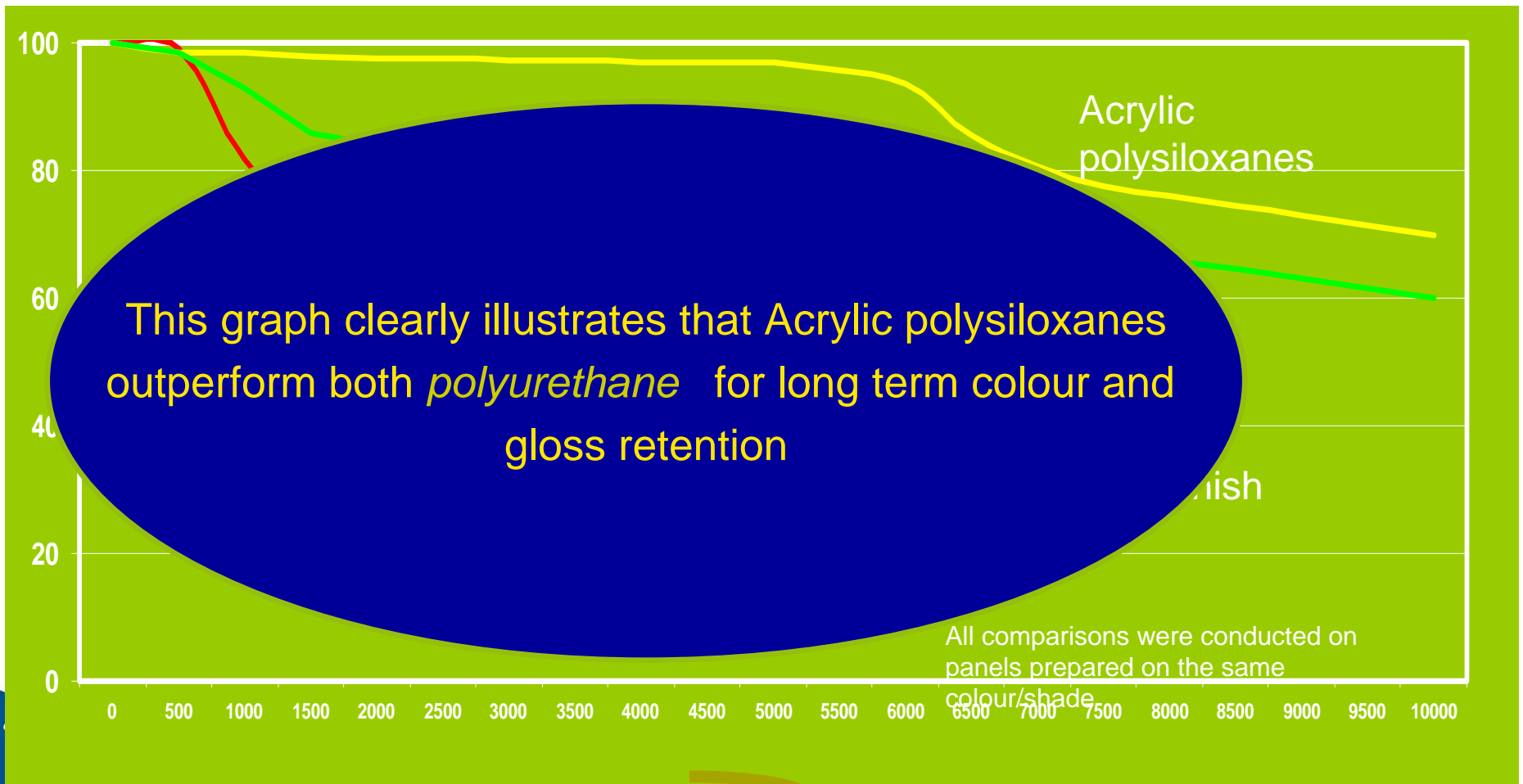
Polysiloxane coatings are significantly more resilient to UV (sunlight) degradation

*The energy required to break the Silicon –Oxygen (Si-O) bond is 452 kJ/mol - **29% higher** than the C-C bond found in traditional coatings*



Durability

- Typically measured as UV resistance on top coats
- Alkyd < Epoxy << Polyurethane <<<< Epoxy Polysiloxane



Silicones

- Primarily used as heat resistant paint, applied at thin film (2 or 3 coats of 20- 25 microns)
- One should not confuse Heat resistant silicone Alumnum paints with corrosion resistant paint
- Heat resistant paints are meant to survive high heat, high heat situations means no moisture in contact with the carbon steel and no or very little corrosion.
- The cyclic temperatures / exposure to atmospheric exposure will require the products to have superior corrosion resistance.
- This is why heat resistant silicone type paints do require anticorrosive primer for long term performance.



Silicates

- Silicates are one of the very few Inorganic coatings (paints) which provide excellent resistance to corrosion/heat in atmospheric exposure situation.
- Can be used as a primer for paint system good enough to provide 10 – 15 years service life prior to need of any major maintenance.
- Necessarily require higher degree of Surface preparation
- Zinc Alkyl Silicate work as a primer while Zinc free materials as top coat for superior heat resistance.
- Blast Cleaning is must --- either use in NB or shutdown.



Epoxies

- Development in Epoxy technology have been most remarkable in terms of providing solution to the problem of corrosion in the verity of situations
 - Atmospheric corrosion
 - Immersion in water, sea water, Chemicals at ambient temperature, and at elevated temperatures. (Tanklinings)
 - Corrosion under Insulation
 - Offshore/ Subsea exposures.
 - Steel, concrete and other substrate



Epoxy/ Epoxy Modifications

- Developments ,both in Epoxy resin and curing material technologies, have been quite significant.
- Not all epoxy paint are same, there are numerous chemistries, combinations and formulating methodologies used to provide suitability for different end uses.
- Liquid epoxies (low Mol Wt) resins based materials find uses in situations like tank linings/ immersion situation, high solids or solvent less epoxies.
- Higher Mol Wt epoxies typically find uses in atmospheric exposure situations,
- Curing Material technologies are equally interesting and provide products provide different properties (Amine/Amine/Phenalkamine /amido-amine/ Isocyanates etc etc



Epoxy – Epoxy Modifications

- Epoxies can be formulated to provide rapid recoat -

Application of three coats possible in one day making it possible to complete a coating system in 1 day.

Application can take place in cold conditions and during winter with virtually no delays while waiting for the epoxy to cure.

- It cross-links at much lower temperatures than normal epoxies, down to 0°C.



Epoxy – Epoxy Modifications

- Epoxy modification/(using internal or external Flexibilization) can be used as surface tolerant Primer
 - Can be applied over Manually cleaned surfaces or tightly adherent Rust.
 - Can be applied on Damp substrates and underwater in some situations
 - In-situ on 'splash zone' – the coating capable of being immersed in water within 15 min of applications at ambient conditions.
 - Single coat Epoxy Primer - Finish suitable up to C4 environment



Epoxy Modifications

- Epoxy resin based materials for back bone of tank linings
 - coatings on the internals of tanks for storing various media
 - Epoxy amine (Polyamine/ Amine Adduct)
 - Epoxy phenolic
 - solventless epoxy
 - Chopped fibre/ Matt based Epoxy linings
 - Epoxy ultra High build coatings/linings

CHEMICAL RESISTANT LININGS/COATINGS



Chemical Resistant Linings

- Technological developments in Polyesters/ Vinyl Esters/ Hybrid vinyl polymers/ Epoxy phenolic/ polycyclamine technologies are able to provide superior solutions.
- These technologies can now be used in the areas where typically other methods of protection e.g. Bricklining, Acid resistant tile lining, Rubber lining have traditionally worked in Chemical exposure situations.



USES: Steel / Concrete

- Process vessel / Equipment/ Tank internal (Wet heat limit 75 – 120 Deg C, 150 Deg C in a few cases), external and under insulation
- Immersion, pH 1.5 – 13
- Floorings
- Piping – internal and external; stacks
- Secondary containment areas, condensing vapors
- Trenches/ sumps
- Effluent treatment
- Flue Gas Ducts
- Metal finishing plants



Chemical Resistant Linings

- Monolithic layers, no Joints
- Many of these are spray applied – much faster speed of application, shorter shut down period
- Lower weight, lesser thickness in comparison to many other methods
- Smooth finish, can be modified to be low surface energy .



Tank Linings

- Unlike coatings for atmospheric exposure, the tank lining or protection in Chemical immersion works slightly differently –
 - Primer – The basic use is to hold the blast profile and provide adhesion to the lining material.
 - Finish coat/ tank lining – This provide chemical resistance and protection to both the substrate (from corroding) and cargo (avoid contamination)

The polymers capability to hold against the chemical and permeability are the 2 major deciding factors for suitability of a lining.



Chemical Resistant Coatings/Linings

Polymers

- Epoxy Resin modifications
- Polyester Resin based
- Vinyl Ester Resin based
- Novolac Co-Polymer based

Use of multiple curing agents along with Epoxy phenolics resins with increase in the functionality (e.g. 4.5 against 2 or 2.5 in traditional epoxy/epoxy Phenolics) coating /lining formulation designed to provide very low permeability



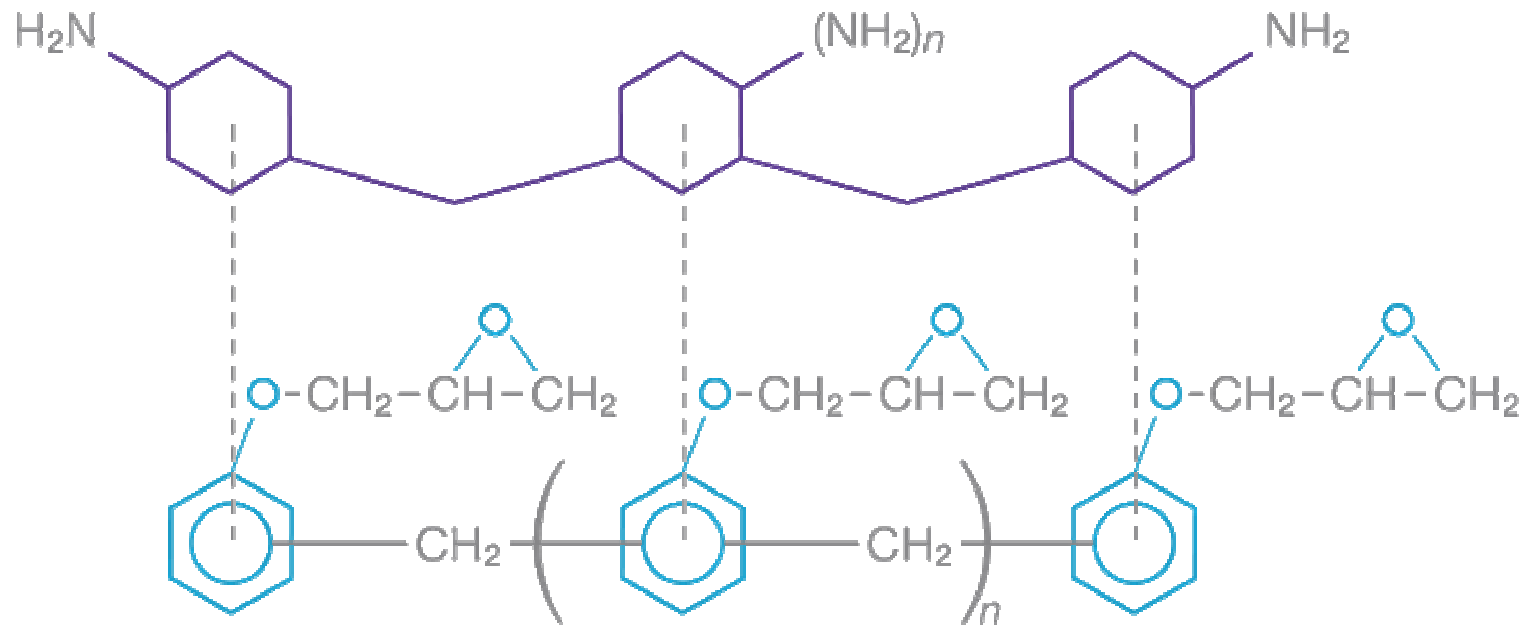
Polycyclamine Cured Lining Technology

- Superior chemical immersion resistance to a wide range of chemicals (including acids, solvents and hydrocarbons).
- High temperature immersion service (120 °C).
- Thick film systems for excellent long-term barrier resistance
- Ultra high solids technology, low to zero VOC's

- It is possible to use these polycyclamine with Bis F epoxy and other modifications to nearly reach the performance of baked phenolics.



Polycyclic amine curative

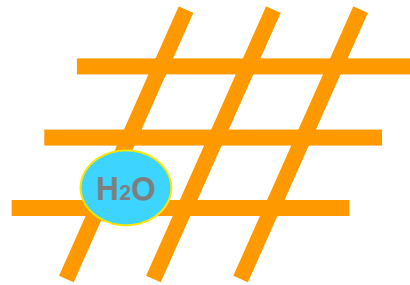


Epoxy Novolac

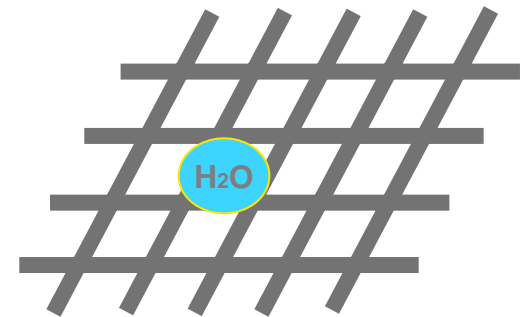


Immersed Temperature Resistance

On heating the free volume in a lining increases in size and eventually allows penetration. Due to increased cross linking polycyclamine cured linings start with smaller free volume and therefore can experience higher temperatures before failure.



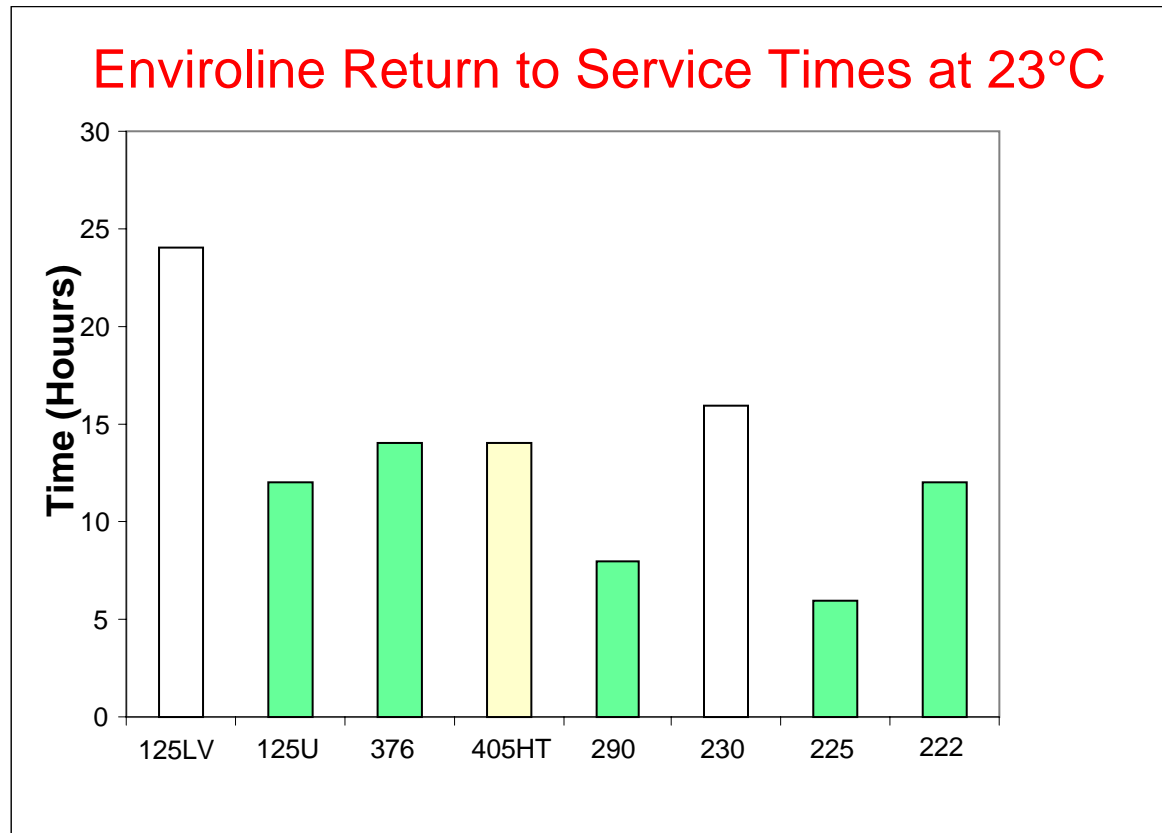
**Traditional amine
cured linings**



**Polycyclamine Cured
Linings**



Return to Service after Lining Application



Extremely short return to service periods

Quick Walk-On Times

Polycyclamine epoxy coatings achieve walk on hardness rapidly (generally within 4 hours), and it is possible to walk on the coating without causing damage:

Inspection and repairs can start soon after coating application, sometimes the same day.

Associated work can also be carried out sooner (e.g. connection of pipe work)

After repairs are complete the coating is ready to return to service in hours not days.



Polyester and Vinyl Esters

- Isophthalic polyesters are the basic option and used either for atmospheric/ambient temperature conditions and Selected life scenerios.
- Use of bisphenol A rethar than Isophthalic option leads to a relatively non polar polyester with reduced number of ester linkages which contributes to excellent corrosion resistance



Polyesters and Vinyl Esters

- Vinyl Esters combine the good properties of Epoxy and polyester both.
- Novolac Vinyl ester resins produced from Novolac epoxies provide much better temperature resistance, and chemical resistance at higher temperature than their vinyl ester and polyester counter parts.



Polymers: Chemical Resistance Test

Polymer	Alkalis	Organic Acids	Inorganic Acids	Aliphatic Solvents	Aromatic Solvents	Chlorinated Solvents
Epoxy Resin	1	3-4	3-4	3-4	2-3	3-4
Polyester Resin	3-4	3	3	3	4	4
Vinyl Ester Resin	2	2-3	1-2	2-3	2	2-3
Novo. Co-Polymer	2-3	1	1-2	1-2	1-2	1

1 – Resistant to maximum concentration

2- Limited resistant

3- Conditional Resistant

4 – Not Resistant

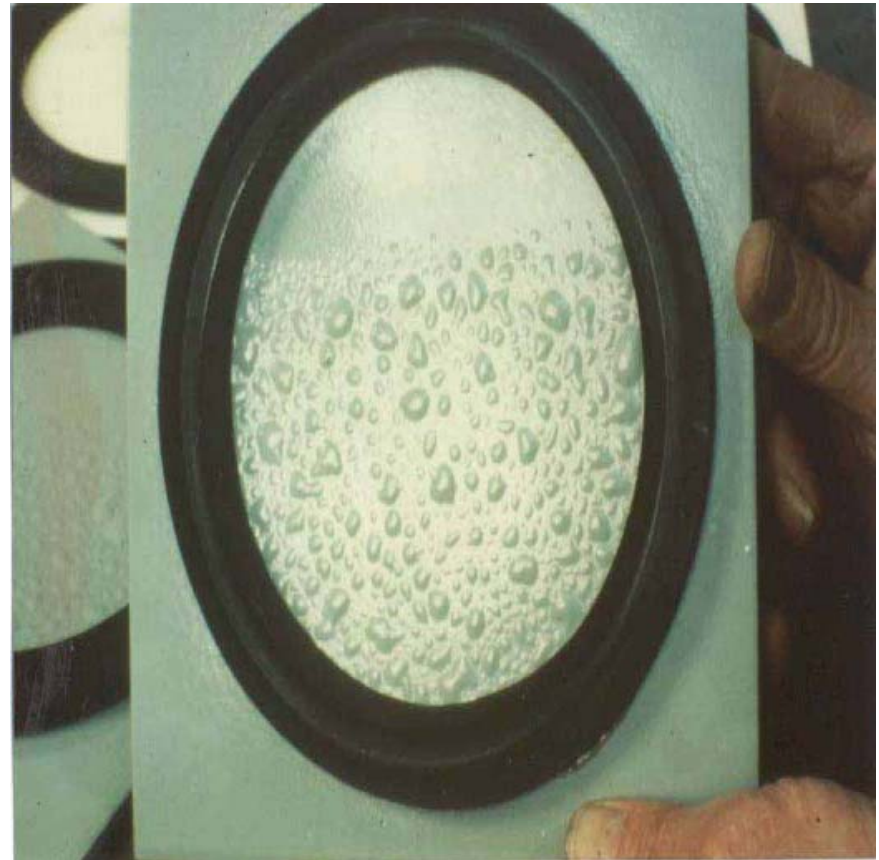


Tests for Evaluating coating/ Lining Materials

- Atlas Cell Test (NACE TM 01 74)
- Chemical immersion Resistance Test
- Heat Resistance Test
- Thermal Cycling Resistance Test
- Abrasion Resistance Test
- Thermal Expansion Test
- Adhesion Test
- Cold Wall Effect



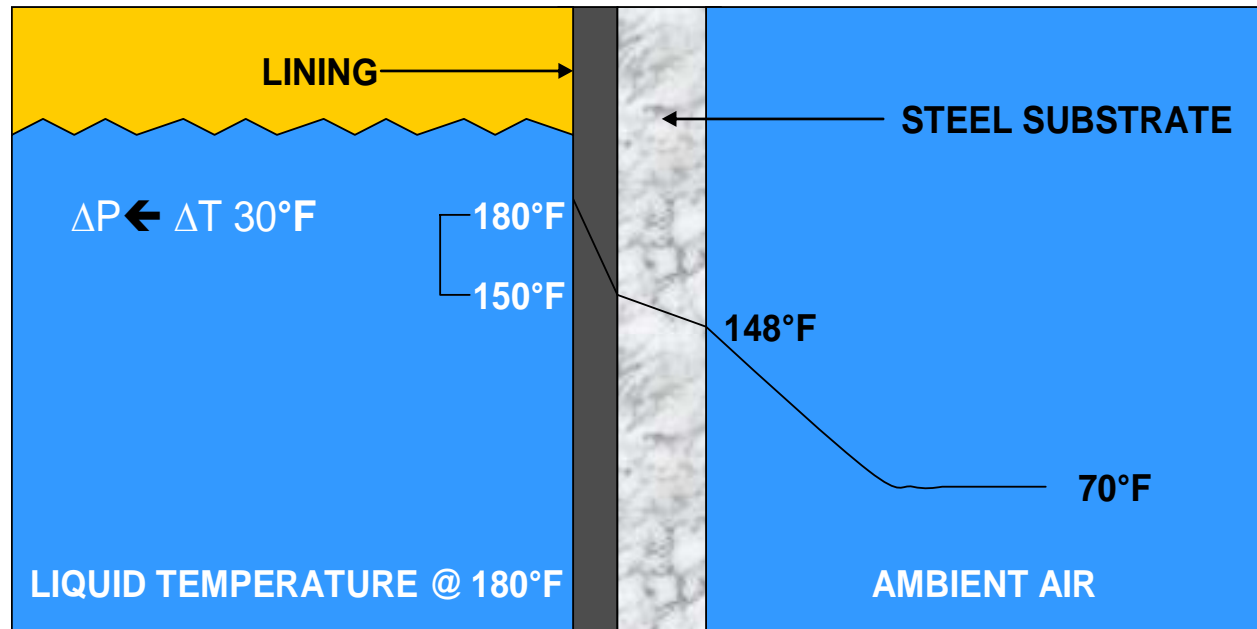
Atlas Cell Test (ASTM C 868- 85)



Water Vapour Permeation Test



Cold Wall Effect



“PROTECTING TOMORROW - TODAY”



Coefficient of Permeation

Coeff. Of Permeation	38°C (100°F)	70°C (160°F)
Flake+ aggregate Filled novolac vinyl ester coating	1.2	2.6
Glass flake Vinyl ester	2.1	4.4
Vinyl Ester Resin (VE)	7.0	15.0
Polyester Resin (UP)	16.0	29.0
Brombutyl Rubber	4.0	9.0
Polychloroprene Rubber	44.0	94.0



Permeability

Permeability of Various Polyester and Vinyl Ester linings

Resin	Filler/Reinforcement	Application	Permeability Perm in. (g/Pa)	Thickness mils	Permeance Perms	Relative Permeance
Novolac Vinyl Ester	1/8" glass flake	Trowel	0.00011	70 mils	0.0016	1
Bisphenol A Polyester	1/8" glass flake	Trowel	0.00022	70 mils	0.0031	2
Novolac Vinyl Ester	1/64" glass flake	Spray or Roll 3 coats	0.0005	54 mils	0.0093	6
Bisphenol A Polyester	Silica filler fiberglass cloth	Trowel	0.0031	150 mils	0.0207	13
Bisphenol A Polyester	Silica filler Fiberglass mat	Trowel base- coat, roll top- coat	0.0044	125 mils	0.0352	22
Bisphenol A Polyester	Fiberglass mat	Roll	0.0078	60 mils	0.13	81



System Temperature Guide

System Build Up	Thickness mils	Max Temp (steel)	Max Temp (concrete)	Service Life
2 Spray Coats small flake	20 mils	120	140	3 to 5
2 Spray Coats small flake (polyester/vinyl ester)	40 mils	140	160	5 to 10
2 Spray Coats small flake (epoxy/epoxy novolac)	40 mils	120/130	140/150	5 to 10
3 Spray Coats small flake (polyester/vinyl ester)	60 mils	160	180	8 to 12
Spray- Matt- Trowel small flake & powder	90 mils	160	180	8 to 15
Trowel- Mat- Trowel powder	140 mils	160	180	8 to 20
Spray- Trowel small flake and large flake (polyester/vinyl ester)	70 mils	150	-	10 to 25
Spray- Trowel small flake and large flake (epoxy)	70 mils	180	-	10 to 25
Trowel -Trowel large Flake (polyester/vinyl ester)	100 mils	210	-	10 to 25
Trowel -Trowel large Flake (epoxy)	100 mils	160	-	10 to 25
* Please note service life varies depending on chemistry, temperature, etc. and may require touch-up repairs and/or re-topcoats				

EXAMPLE - Whirlpool Clyde, Ohio -water boxes were coated with Ceilcote 600 Flakeline in 1964. They were inspected and still in good shape. It was decide to extend thelife further a new topcoat of Ceilcote 600 Flakeline is to be installed



Typical Chemical Resistance list

- Can take typical pH of 1.5 – 13, depending on Chemicals and temperature
- 93 – 98% H₂SO₄ at ambient temperature
- Flue gas up to 240 Deg C
- 37% Hydrochloric Acid
- Nitric Acid 40%
- Glacial Acetic Acid
- Brine, saturated chlorine water
- Chloroacetic Acid (50%)
- Dimethyl aniline, Cyclohexane
- Formaldehyde



High Heat/ Corrosion Under Insulation

High Heat Coatings

- High Heat conditions are found in a large number of situations.
- Steel will not corrode at high temperatures
- Protection is required for the following situations
 - transportation to site and installation (temporary protection)
 - equipment shut down
 - temperature cycling
- Selection of coating is dependant on the operating temperature
- Under Insulation is a specialized situation and careful coating selection is required



High Temperature Resistance

Steel components operating at high temperatures can be classed into two groups

- Those which are *uninsulated*
- Those which are *insulated*

In both cases, continuous, hot, dry conditions provide a relatively non-corrosive environment, and only heat resistance is required

However, when temperatures fluctuate or cycle, whereby cooler, wet conditions are possible, corrosion can occur



High Heat Situations

- Problem, arises in the when there is a variation in temperature involved –
 - at lower temperatures, the corrosion starts, as moisture sits on the surface
 - at temperatures below dew points, acid starts depositing on substrate (e.g. in stacks/ chimney internals)
 - thermal stress on coatings due to temperature
 - variation may result in coating failure



Corrosion Under Insulation (C.U.I.)

- The presence of moisture in contact with **uninsulated** steelwork has the opportunity to 'evaporate off' into the atmospheric environment
- However, the presence of moisture in contact with **insulated** steelwork via wet insulation, may not have the opportunity to evaporate off, and gets trapped beneath the insulating material
 - **No insulating material is 100% waterproof, moisture can, and does find its way toward the steel substrate**
- This combination of steel, trapped moisture, contaminants and oxygen ensures all the ingredients are there for corrosion to start. The result being
 - **CORROSION UNDER INSULATION (C.U.I.)**
- Throw in the temperature cycling variable and you now have the perfect conditions for rapid corrosion to occur resulting in fast metal loss
 - **The most critical temperature range is between - 4°C to 150°C (25 to 302°F)**



Heat Resistance Polymers

- Traditional epoxy binder based products have a limited temperature resistance upto around 120°C (250°F). At temperatures greater than 120°C (250°F), the binder begins to thermally degrade resulting in coating breakdown
- *Epoxy-phenolic* binders differ from *epoxy* in that they have an increased number of reactive sites which allows a more '*densely*' crosslinked coating film to form
- This '*densely*' crosslinked film brings with it improved properties, one being an *increase in thermal stability* as compared to standard epoxies.



High Heat Polymers

- Modified Novolac vinyl esters also protect up to a temperature of 200 – 300 Deg C Dry heat resistance.
 - Excellent heat resistance
 - Excellent resistance to chemicals, acids

- Silicone resin based coatings –
 - General products require heat curing between coats and after completion
 - Very sensitive to over application
 - Limited corrosion resistance
 - moisture curing silicone resin based coating have practical benefits over conventional silicone resin based materials



Silicone High Heat Coatings

- General products require heat curing between coats and after completion
- Very sensitive to over application
- Limited corrosion resistance
- Require heat resistant primer to provide long term protection.

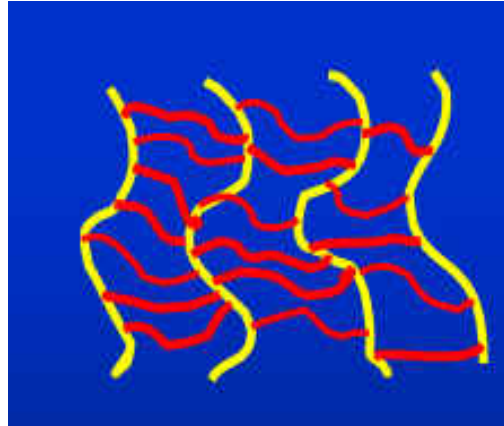
- Coating Failures occur very regularly on manually cleaned surfaces



About Epoxy – Phenolic Binders

- The densely crosslinked film provides an *excellent barrier to moisture ingress*
- This results in a combination of excellent corrosion resistance at ambient and elevated temperatures

Moisture finds it difficult to penetrate the dense crosslinked film



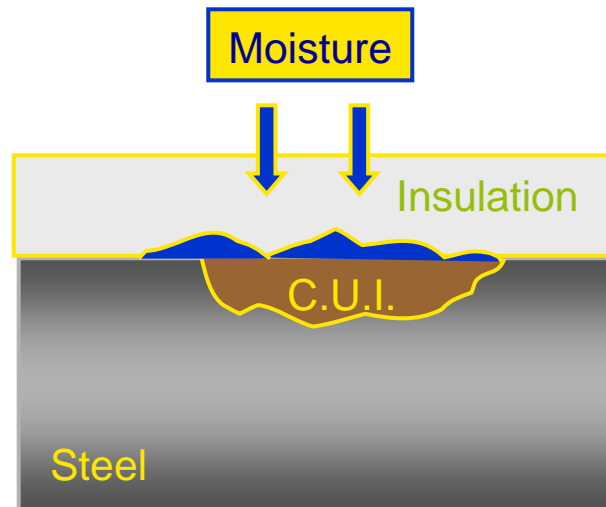
High build
2 x 100µm (4 mils) dft

provides excellent corrosion protection for high temperature steelwork under thermal insulation

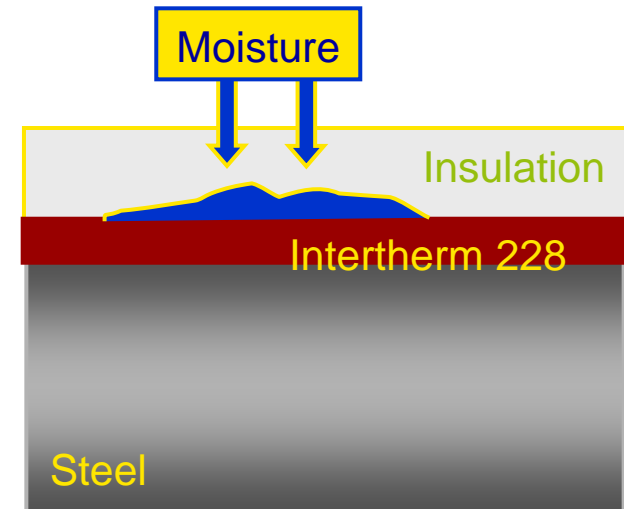


Corrosion Under Insulation (C.U.I.)

The danger of C.U.I. is that it can occur without visible detection



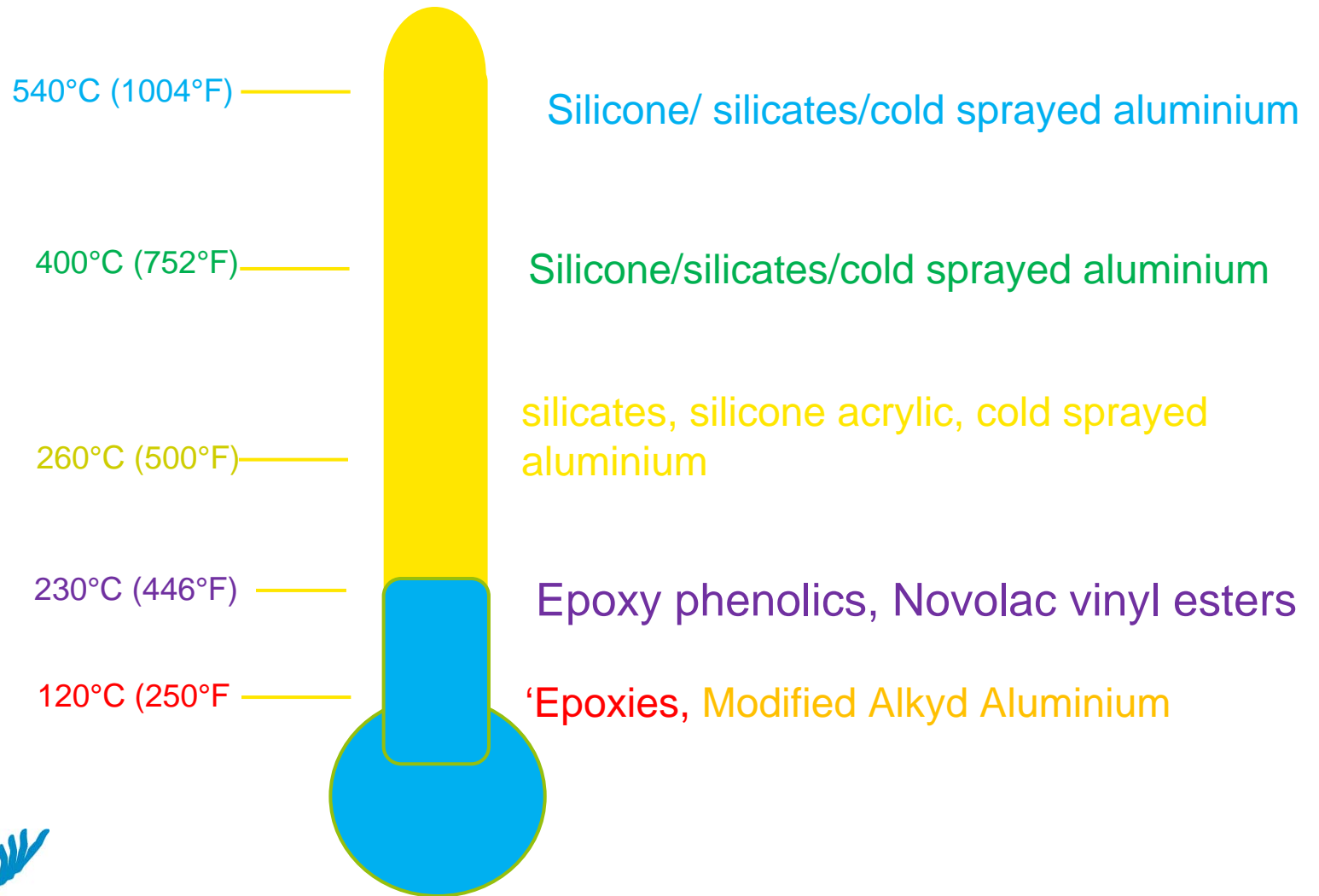
Corrosion under insulation causes
Rapid metal loss which significantly
Shortens the lifetime of the steel
structure



The use of epoxy phenolics provides
An excellent barrier to moisture, thus
preventing C.U.I. and extending steel
Structure design life



Technology Positioning – Temperature Resistance



How to Choose Correct Coatings Scheme?

Checklist for Choosing correct coatings scheme

- Define your in-service environment (C1, C2 etc)
- Define Durability ... (low, medium, high)
- Use a reputable, international standard to give a recommendation on the type of system(s) that might be appropriate
- Ask the supplier to name his systems to meet your criteria
- Ask the supplier to provide test data to a recognised international standard to back up his claims on his proposed systems
- You don't need generic equivalence: Name the systems and suppliers (get the best from each supplier)
- Choose the actual system applied at contract stage not at specification (leave a menu)
- Ensure that samples tested match the material supplied (fingerprint)



Conclusion

- High Performance Protective coatings offers the economical solution to corrosion prevention
- When properly prepared and applied they extend the service life of structures by considerable period
- Many advancement in protective coating technology has taken place which can be adopted in New construction and M&R situations to rationalize life cycle cost of assets management.



Questions ?



END

Thank You

