

SURFACE PREPARATION - THE IMPORTANCE ON COATING PERFORMANCE

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SUMMARY:

1. The end use design for conventional epoxy formulations is generally aimed at new construction work where the coating will be required to exhibit high build application in few coats, rapid turn and recoat of the substrate, high abrasion, impact resistance and possibly chemical resistance. These coatings need surface preparation to AS 1627.4 Sa 2½ or better with an adequate surface profile to maximise their durability.
2. The end use design for epoxy mastics used in the protective coatings industry is generally aimed at maintenance of older coatings or repair of coatings where they have failed in sections. The longer surface wetting properties of these coatings allows time for the resin to penetrate into and past residual corrosion and older coatings so the requirements for surface preparation can be lessened. The design requirements of epoxy mastics used in the marine industry differs because application to large block sections that will not be rotated, handled or re-coated for some months favours the epoxy mastic with its long recoat times while not needing some of the properties of a conventional epoxy.
3. While the adhesion of epoxy mastics is superior to residual rust, corrosion product and old coatings, the integrity of the underlying layer cannot be assured and for this reason the highest possible level of surface preparation is recommended for all cases.

Keywords: Epoxy Mastic; Conventional Epoxy, Adhesion, Surface Profile.

1. INTRODUCTION

For more than 15 years the protective coatings industry has spent a lot of time and money in developing 'Epoxy Mastic' coatings that are promoted as distinguishing themselves from 'Conventional Epoxy' coatings because of their tolerance to application over a less than perfectly prepared surface (substrate). These epoxy mastic coatings feature ease of recoating when weathered and aged. Development of these coatings in the protective coatings industry has mainly concentrated on carbon steel as the primary substrate.

Considering this, you may ask why is it that all major coating manufacturers still specify that steel for new projects as well as (when possible) maintenance projects should receive optimum surface preparation such as abrasive blasting to AS 1627.4 2005 Sa 2½. (ISO 8501-1 Sa 2½; SSPC SP 10 / NACE No. 2).

You may ask, if the new generation of Epoxy Mastics are so good, why can't they be applied over a surface that has not received optimum surface preparation without any performance loss?

To help answer this question, macro photography was used to show the cross section of a conventional epoxy and an epoxy mastic applied to a carbon steel plate prepared to AS/NZS 1627.2 St2 and AS/NZS 1627.4 Sa 2½.

A plate of carbon steel conforming to AS 1627.4 Grade C was prepared to AS 1627.2 St 2 and St3 and AS 1627.4 Sa 1 and Sa 2½. and coated with a conventional epoxy and an epoxy mastic. Adhesion testing by pull off method was conducted to see if there were differences in the adhesion of both types of epoxy to the four grades of preparation.

2. HISTORY

Prior to the invention of abrasive blasting, painters would prepare a steel surface for painting by hammering at rust and mill scale, chipping at it, applying heat by flame, acid pickling, needle guns and other inventive impact tools in an attempt to remove as much of the mill scale and surface rust as was possible.

Experience had shown that painting over the mill scale was a waste of time as moisture penetration through the coating, taking with it oxygen would initiate osmotic blistering and corrosion resulting in detachment of the mill scale from the underlying carbon steel which took the paint with it.

The marine industry would allow a newly constructed steel ship to weather for several months in order to allow as much of the mill scale as possible to fall off the steel. Then they would paint.

We now know that mill scale is electro-chemically cathodic to steel [1] and any break in the mill scale coating will cause accelerated corrosion of steel exposed at the break as the steel degrades to protect the mill scale. This results in the mill scale becoming detached and falling off along with the paint cover. This process is the reverse of the protection afforded carbon steel when zinc based coatings are applied to clean carbon steel when mill scale has been removed.

The introduction of red lead primers helped the performance of coatings applied over mill scale because red lead is an oxygen scavenger [4] and showed that it was capable of protecting the otherwise unstable mill scale for extended periods, often as long as 10 or more years.

Red lead primers were officially withdrawn in Australia in 1991 when the then Government Paint Committee (now APAS) withdrew all approvals for lead in paints.

Long before the withdrawal of red lead paints the industrial abrasive blasting industry had commenced and was well developed in manual and automatic blast methods which allowed quick, efficient and cost effective removal of mill scale.

This efficient method of mill scale removal negated the requirement for coatings such as red lead. Coatings were then developed to protect the steel by chemical reaction (zinc phosphate), galvanic means (zinc rich primers) or by envelope barrier coatings (epoxy and other) to isolate the steel from the environment.

3. ZINC RICH PRIMERS

Much is already written and known about organic and inorganic zinc rich primers and most manufacturers specify that the required surface preparation for these materials is AS 1627.4 Sa 2½ (ISO 8501-1 Sa 2½, SSPC SP 10/NACE No. 2) to provide a good anchor pattern on the substrate as well as to set up an efficient electrical contact between the zinc in the primer and the substrate steel. Zinc rich primers are not discussed further.

4. TRADITIONAL EPOXY PRIMERS

Before the development of epoxy mastics, conventional epoxy primers and epoxy coatings designed for direct to metal application relied heavily on a very clean surface that was roughened with a high enough profile to provide the coating an anchor pattern. The common standard of preparation specified was AS 1627.4 2005 Sa 2½ with a surface profile of 35-55 microns.

These original formulations did not have excellent wetting properties, so any residual corrosion, mill scale or other loose contamination would impede the coating's adhesion and therefore the performance of the coating.

5. ADHESION

To obtain good adhesion a coating relies on intimate contact with the substrate as well as a surface profile.

Adhesion is created by physical and chemical forces which interact at the interface of the coating and the substrate.[2]

Epoxyes have chemical radicals within the molecule which have a strong affinity for metal surfaces. These are often called *polar molecules*. [3] It makes sense to clean the steel of any contamination that may interfere with this chemical reaction.

6. CURE

Early model epoxyes also cured to a very hard state and this made re-coating the aged coating very difficult without abrasion to re-profile the surface. Successful recoating was also affected by the mediocre wetting properties of the fresh material.

It was common to see specifications for re-coating a traditional epoxy to require abrasion by hand, machine or abrasive blasting to SSPC SP 7 / NACE No. 4 Brush-Off Blast Cleaning which brought mixed results. If the coating did not shatter, the surface profile produced was generally higher than the original profile on the steel so a lot of new coating was used filling this dead zone of the surface profile before the actual film thickness could be built. This added to the cost per m².

Being very hard coatings, there was a danger that, during brush blasting, the coating may develop micro-cracks that were not visible. The micro-cracks weakened the original coating's adhesion and reduced the durability of the new coating applied to the weathered coating.

Because of the unknown performance of applying new epoxy over old, many applicators elected, when possible, to fully remove the coating with a full blast and to fully reapply the coating system.

7. CHLORINATED RUBBER & PVC VINYL COATINGS

Before the development of the epoxy mastic, alternative coatings to epoxy were solvent borne Chlorinated Rubber or PVC Vinyl. Apart from their superior chemical resistance and acceptable UV resistance, they could be overcoated with minimal surface preparation because they were solvent sensitive. A new coat could be cold vulcanized to the old by melting itself into the surface of the aged coating. In many cases the only surface preparation required was a thorough wash down.

The impending Volatile Organic Compound (VOC) regulations of the day encouraged coating manufacturers to develop coatings to replace those with very high VOC's such as the chlorinated rubber and vinyl's. Epoxy based coatings were seen as a good replacement because of their low cost and global availability.

8. FORMULATION REQUIREMENTS FOR EPOXY MASTIC

If the new epoxy coatings were to give the same benefits as the traditional chlorinated rubber and vinyl coatings the formulator's had to change some of the traditional features of a conventional epoxy coating.

The following requirements were accepted for the design.

- Must be surface tolerant so that the coating adheres well to old coating, intact rust and surfaces that have not received optimal surface preparation;
- Must be recoatable with itself after initial cure and after weathering and ageing;
- Must be able to be applied in fewer coats than the materials it was to replace; and,
- Must be low in VOC.

Today's generation of epoxy mastic coatings meet these requirements and now perform as well as conventional epoxy formulations in some very aggressive environments such as ballast tanks in ships. In general, epoxy mastic's do not have the chemical or abrasion resistance and dry / cure times equal to conventional epoxy coatings.

So, if epoxy mastic's adhere to a compromised surface and so well to themselves, you may ask why do we still call for high level surface preparation?

9. MILL SCALE

The argument 'do not overcoat mill scale' is still very valid. Therefore, specifying that the mill scale must be removed by abrasive blasting is a valid treatment requirement for new steel. Much of the steel used today in both marine and structural steel fabrication has been treated to remove the mill scale by abrasive blast cleaning in a blast yard or in a plate shop. In nearly all cases the plate is also primed with a thin film weld through construction primer to give temporary protection to the steel during construction.

When maintaining previously coated steel it is very likely that the steel that is to be maintained will have previously been cleaned to remove the mill scale.

10. RUST

What about rust? Rust is iron oxide and chemically different to mill scale. It is here that we look at the potential differences in coating performance.

What happens when you coat over (intact) rust?

11. WETTING PROPERTIES

The wetting properties of modern, conventionally pigmented epoxy coatings are much improved on earlier models and when applied correctly the conventional epoxy of today will develop good adhesion to residual rust. However, they are just not as

reliable as an epoxy mastic and application needs to be accurate to get a consistent result when the surface condition is compromised.

The distance from the spray gun tip to the substrate is more important with a conventional epoxy than an epoxy mastic. If the distance increases too far the following can occur: -

This photo shows a cross section of a conventional epoxy coating applied over a primer coat where the coating has not flowed and a void has formed

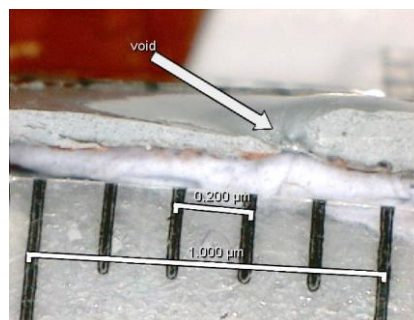


Figure 1

12. DRY AND CURE TIMES

An indication of the differences in the dry and cure times between a conventional epoxy and an epoxy mastic can be demonstrated by comparing the technical data sheet of each product.

Table 1. The dry and cure times for a typical conventional epoxy

Substrate temperature	10°C	23°C	40°C
Surface dry	5 h	2,5 h	1 h
Through dry	16 h	8 h	3,5 h
Cured	14 d	7 d	3 d
Dry to recoat, minimum	16 h	8 h	3,5 h

Table 2 The dry and cure times for a typical epoxy mastic

Substrate temperature	10°C	23°C	40°C
Surface dry	18 h	7 h	2 h
Through dry	24 h	10 h	4 h
Cured	14 d	7 d	2 d
Dry to recoat, minimum	24 h	10 h	4 h

Generally, the epoxy mastic stays wet for a longer time than the conventional epoxy.

13. THE ADHESION OF CONVENTIONAL EPOXY TO CARBON STEEL

To see what is happening when a coating is applied to the substrate it is handy to use macro photography to examine the cross section of the applied coating.

The following macro photographs show cross sectional images of a polyamide cured conventional epoxy applied to carbon steel prepared to AS 1627.4 Sa 2 ½ and AS 1627.2 St 2. Magnification is x 200 and x 500 as noted on each photograph. Photos have added colour to assist the viewer distinguish the various cross sections of the photograph.

This photograph shows the classic AS 1627.4 Sa 2½ surface profile with a conventional epoxy applied to the clean steel. Surface wetting is good and the surface roughness gives an efficient anchor pattern for the coating.

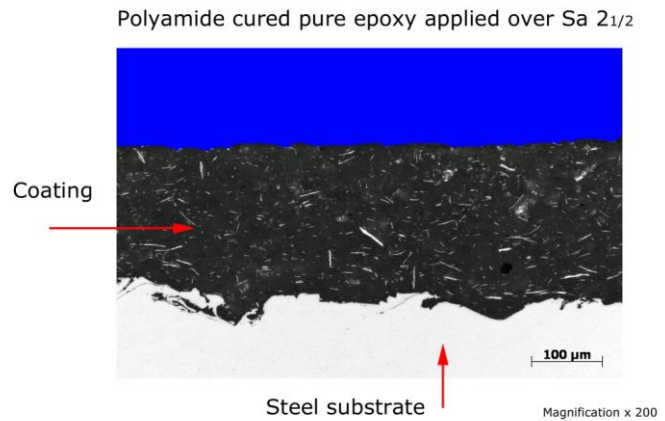


Figure 2

This photograph shows the steel substrate is covered with a residual layer of intact corrosion product (rust). Sitting on top of the intact corrosion are two smaller areas of loose corrosion product. The polyamide epoxy has covered the residual corrosion but it lacks penetration into the corrosion layer and has not penetrated the loose corrosion areas.

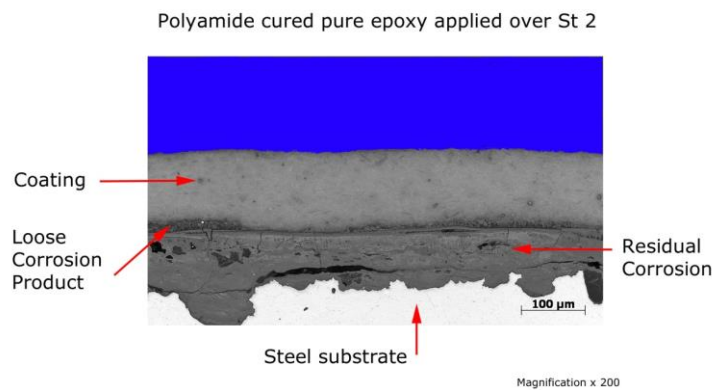


Figure 3

This photograph is a segment enlargement of figure 3 showing the area of loose corrosion product overcoated by the conventional polyamide epoxy.

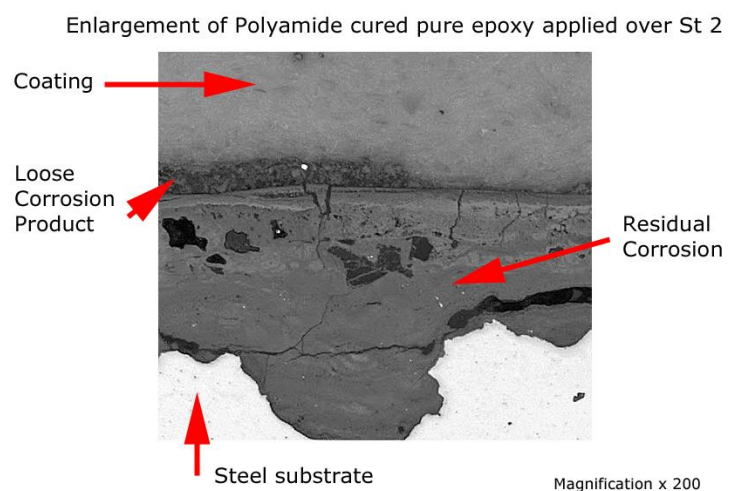


Figure 4

Figure 5 is a x 500 magnification of the same area of loose corrosion product in Figure 3 and the underlying intact corrosion. How intact is this corrosion?

At this magnification it is possible to see stress cracking in the layer of corrosion.

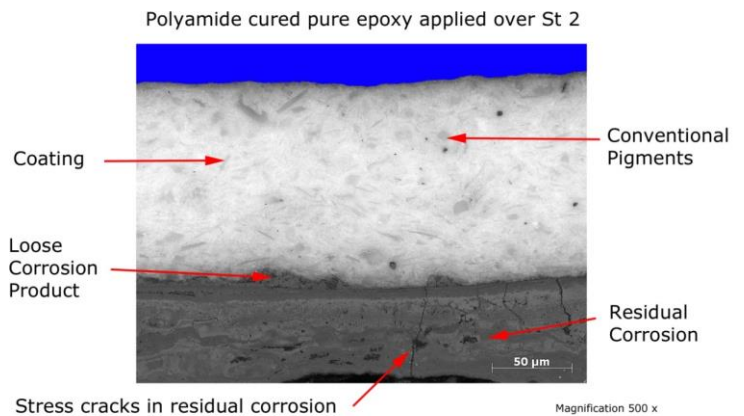


Figure 5

14. THE ADHESION OF AN EPOXY MASTIC TO CARBON STEEL

The wetting properties and resin penetrating properties of a modern epoxy mastic are much better than a conventional epoxy. Unfortunately, to get those properties we have to sacrifice some of the other better properties of a conventional epoxy so today all manufacturers have both types of epoxy on offer and selecting where they are used and when they are used is a matter of matching their properties to the exposure conditions and durability requirements.

The following photographs show cross sectional macro photographs of a polyamine cured aluminium pigmented Epoxy Mastic applied to carbon steel prepared to AS 1627.4 Sa 2 ½ and AS 1627.2 St 2. Magnification is x 200 and x 500 as noted on each photograph.

Figure 6 shows a polyamine cured aluminium epoxy mastic applied over carbon steel cleaned to AS 1627.4 Sa 2½. The classic surface profile is seen with the coating wetting and effectively adhering to the profiled surface.

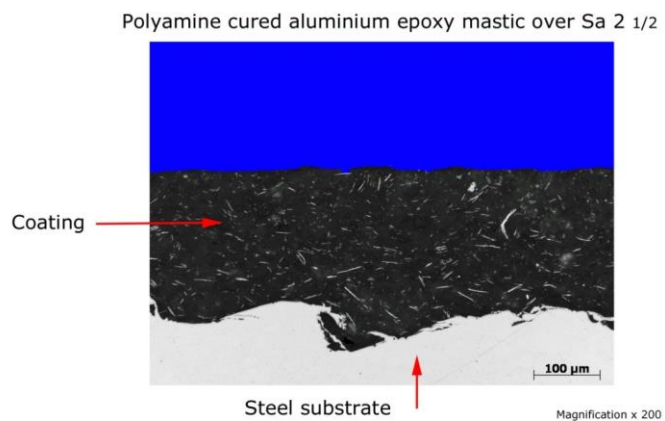


Figure 6

Figure 7 shows the same epoxy mastic applied over a carbon steel surface prepared to AS 1627.2 St 2. There is a layer of intact corrosion product and a thinner layer of loose corrosion product sitting between the intact layer and the coating.

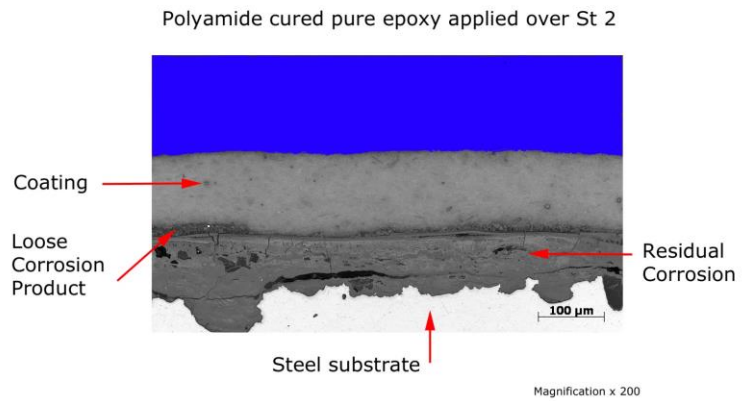


Figure 7

Enlargement of x 200 magnification

Photograph 8 is a sectional enlargement of photograph 7 showing the layers of corrosion product and stress cracks and voids in the corrosion layer.

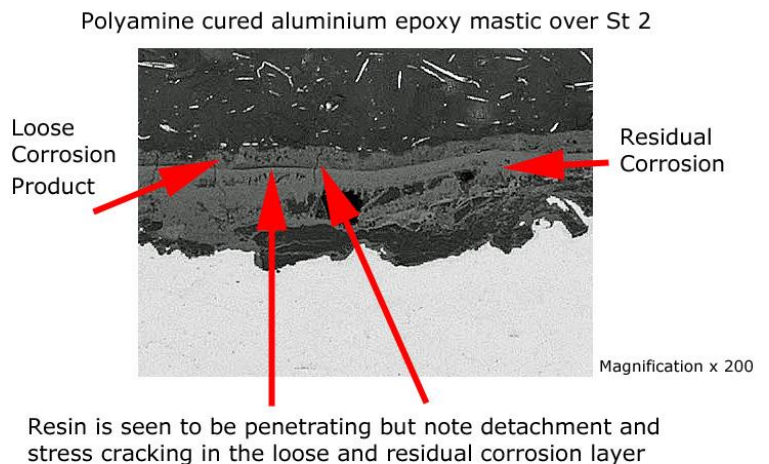


Figure 8

Figure 9 is a sectional enlargement of figure 8 which shows the very resinous layer of the epoxy mastic well attached to the corrosion layer. The crack in the corrosion layer appears to be well filled by resin.

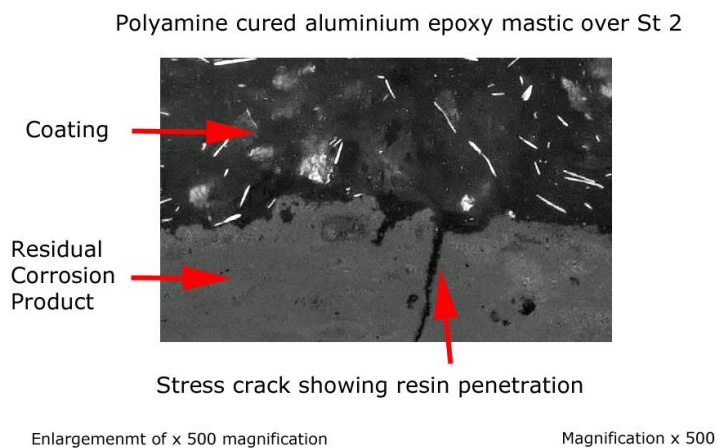


Figure 9

15. COMPARISON OF ADHESION BETWEEN COATING TYPES

When we visually examine the adhesion of both conventional and epoxy mastic coatings to steel which has been abrasive blast cleaned to AS 1627.4 Sa 2 1/2 the results look the same. Both coatings have wet the surface and surrounded the profile and are well anchored to the surface.

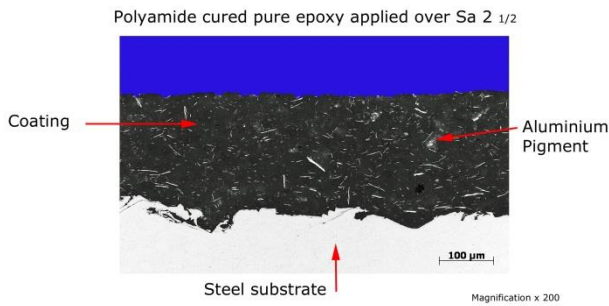


Figure 2

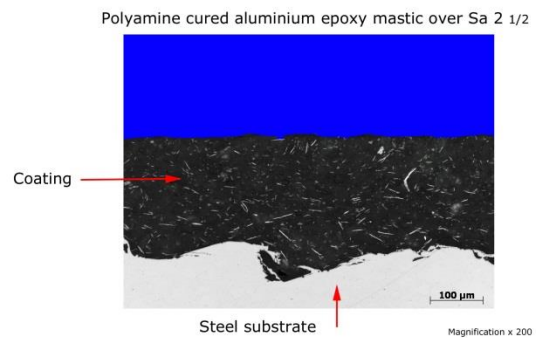


Figure 6

The adhesion of the conventional epoxy and epoxy mastic to a surface prepared to AS 1627.2 St 2 is less definitive, although the epoxy mastic shows better penetration into the loose corrosion and stress cracks.

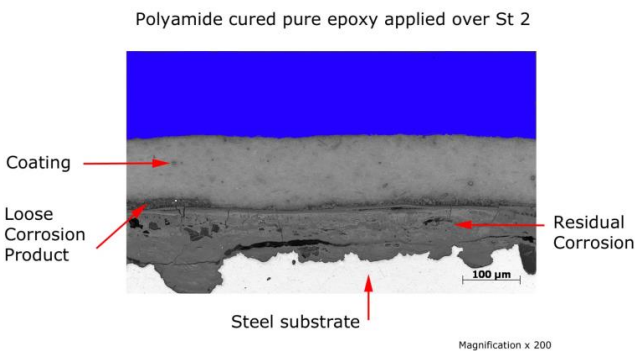


Figure 3

Enlargement of x 200 magnification

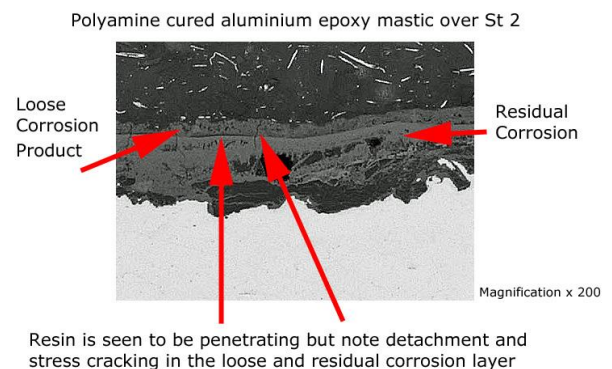


Figure 8

If both epoxy types can be applied over rust, why should I use Epoxy Mastic?

16. COATING POROSITY AND TRANSFER OF MOISTURE VAPOUR

All coatings are porous. In fact, one of the measures of a coating's performance is the time it takes for moisture vapour, taking with it dissolved water molecules and oxygen to penetrate a coating to the substrate and sooner or later osmotic blistering may be observed. If salts were not removed from the surface before coating the osmotic blistering will lead to the formation of an electrolyte under the coating and corrosion will then initiate.

We can slow the rate of penetration by adding film thickness or by adding pigments such as the aluminium pigment shown in these photographs to slow the moisture progress through the film. Three of the most common pigments used to establish a torturous pathway within the coating film are micronised glass flake, aluminium and micaceous iron oxide.

When we add a large quantity of either pigment to a conventional epoxy we find the adhesion to a poor surface diminishes.

We also find that epoxy mastics readily accept platelet pigments and still maintain their good wetting ability and adhesion to poorly prepared surfaces.

If the performance of the coating is measured by the permeation rate, it makes sense to use barrier pigments in maintenance coatings when they are applied over compromised surfaces so that the superior adhesion of these resins is complimented by the additional barrier effect of the pigment.



Figure 10. Micronised Glass Flake



Figure 11. Micaceous Iron Oxide

If the adhesion of epoxy mastic is good to a compromised surface and the addition of barrier pigments further improves the coating performance, why is it better to apply the coating over a surface prepared to AS 1627.4 Sa 2½?

17. INTEGRITY OF THE INTACT CORROSION LAYER

To answer that question we need to look at what is going on below the coating.

In figure 4 we see a cross section of a coating applied over rust. The surface was prepared to AS 1627.2 St 2.

In figure 4 we can see there is a small crack between the residual rust and the steel substrate. The coating is adequately adhered to the rust but the rust is not well adhered to the steel. Here is the weak point in the system.

We have formulated the coating to adhere well to the rust but we can't control the adhesion of the rust to the steel.

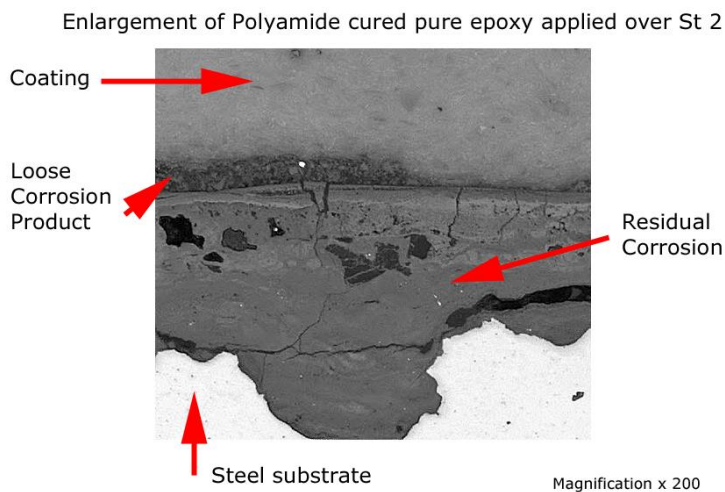


Figure 4

18. COHESIVE STRENGTH OF THE COATING

As solvent borne coatings dry and cure they release solvents and dimensionally shrink. Even solvent free coatings shrink. Part of good coating design is to ensure that the adhesive strength of a coating is sufficient to resist the cohesive strength of the coating as it cures so that the coating does not shrink to a point where it overcomes the coating's adhesive strength and detaches from the substrate.

If the coating is applied to residual rust which has poor adhesion to the underlying steel, the adhesion of the coating may be sufficient to hold on to the rust layer but the cohesive strength may be able to defeat or weaken the adhesion of the corrosion layer which can lead to early failure and poor resistance to impact and abrasion damage.

19. INITIATION OF CORROSION

When moisture does eventually penetrate the coating it will meet the layer of existing rust which will most likely have some residual salts present which will lead to the formation of an electrolyte and initiation of corrosion will follow. This will lead to the formation of new rust which will add to the bulk under the coating. The additional rust formation will dislodge the existing rust layer, pushing upwards to crack the coating and allow free ingress of water to accelerate the corrosion process.

Alternatively, if moisture and oxygen penetrate the coating to a fully clean surface the corrosion by-product will take longer to develop and push the coating off the steel. This buys time.

20. CAN THE REDUCTION IN ADHESION OF A CONVENTIONAL EPOXY APPLIED OVER A LESS THAN PERFECT SURFACE BE DEMONSTRATED?

A conventional epoxy coating and epoxy mastic coating was applied to a steel plate prepared in segments to AS 1627-2 St 2; St 3, AS 1627.4 Sa 1 and Sa 2½.

The conventional epoxy was applied in two coats to achieve 500µm DFT and allowed to cure for 7 days in Brisbane, Australia spring weather conditions of approximately 18-29°C.

The epoxy mastic was applied in two coats to achieve 800µm DFT and allowed to cure for 7 days in Brisbane, Australia winter weather conditions of approximately 10-21°C.

Two adhesion dolly's were attached to each section of the plate using Araldite Standard two part epoxy adhesive and the adhesive was allowed to cure for another 7 days in the same weather conditions.

20.1 Note on adhesion testing standards

Examination of three regularly quoted Standards for adhesion testing of coatings shows the following summary: -

Table 3. Variations between Standards regarding cutting around the Dolly

Standard	Comment on Cutting around the Dolly
ISO 4624	Cut when coating system is above 150 µm
ASTM D 4561	Do not cut
AS 3894.9	Cut when over 500µm using electric drill but omit for "Rigid Coatings"

As can be seen, none of these standards agree with the other and reflect the individual committee's range of opinions on whether to cut or not to cut around the dolly.

For this test it was decided to cut around one dolly per section and to leave the other as placed and test both to see if the adhesion rate returned different values.

21. ADHESION TEST RESULTS

Table 4. The adhesion values for the 4 segments of the Conventional Epoxy.

Segment No.	1	2	3	4
Surface Preparation	St 2	St 3	Sa 1	Sa 2½
Average DFT µm after sanding	530	490	513	484
Adhesion MPa Dolly 1 (cut)	9	10.66	15.33	17.45
Failure Type to ISO 4624	A95, B5	Y5, A30, B65	Y/Z5, A20, B75	Y/Z45, B55
Adhesion MPa Dolly 2 (not cut)	10.72	13.00	18.26	18.75
Failure type to ISO 4624	A95, B5	Y/Z5, A40, B45	Y/Z50, A5, B45	Y/Z10, B90
Average Adhesion MPa	9.86	11.83	16.69	18.1

Adhesion tester used was a DeFelsko® PosiTest AT-A. Calibration Certificate No. 12-263357 18-04-2012

The steel plate temperature at the time of testing was 28.3°C.

The air temperature at the time of testing was 28°C.

21.1 Interpretation of Adhesion Results-Conventional Epoxy

The adhesion results show that as the surface preparation improves, so does the adhesion. Also, the failure type shows a large percentage of (A) cohesive failure of the substrate or the rust line splitting for preparation grades St 2 and St 3. The failure mode for Sa 1 and Sa 2½ moves more to cohesive failure of the coating which indicates a higher adhesion rate of the coating to the substrate when the class of surface preparation improves. The adhesion result when the dolly is cut is lower than when not cut.

Table 5. The adhesion values for the 4 segments of the Epoxy Mastic.

Segment No.	1	2	3	4
Surface Preparation	St 2	St 3	Sa 1	Sa 2½
Average DFT µm after sanding	953	919	934	996
Adhesion MPa Dolly 2 (cut)	17.29	17.27	17.06	13.89
Failure Type to ISO 4624	B 97, Y/Z 3	Y/Z 98, B 2	A/B 70, Y/Z 30	Y/Z 90, B 10
Adhesion MPa Dolly 1 (not cut)	18.47	18.35	18.90	17.66
Failure type to ISO 4624	Y/Z 50, B50	Y/Z 98, B 2	Y/Z 65, A/B 35	Y/Z 90, B 10
Average Adhesion MPa	17.88	17.81	17.98	15.77

The steel plate temperature at the time of testing was 22.3°C.

The air temperature at the time of testing was 22.4°C.

21.2 Interpretation of Adhesion Results-Epoxy Mastic

The results indicate that the adhesion of the epoxy mastic is greater than the conventional epoxy for segments St 2, St 3 and Sa 1 and slightly less than the conventional epoxy for Sa 2½. The failure mode for the Sa 2½ section was adhesive failure to the dolly so another test may have shown a different result. The results show somewhat equivalent adhesion for segments St 2, St 3 and Sa 1, indicating the ability of the epoxy mastic to penetrate residual corrosion in these segments. Also, the failure type shows a large percentage of Y/Z adhesive failure between adhesive and dolly which indicates the epoxy mastic has better adhesive strength than the adhesive.

22. CONCLUSIONS

1. The macro photography and adhesion sample rate is too small to absolutely show that the adhesion of epoxy mastic coatings is better on a compromised surface than it is for a conventional epoxy. However, the samples do show this is likely.
2. The epoxy mastic demonstrated the formulation design of having superior adhesion to a compromised surface but no better than the conventional epoxy over a surface prepared to Sa 2½.
3. Cutting around the dolly resulted in lower adhesion values.
4. Mill scale should be removed at all times as modern coatings cannot provide the same protection to the underlying steel as did traditional red lead paints when the mill scale is left on the steel
5. Conventional epoxy and epoxy mastics have different application and performance properties and should be chosen for use where those properties are best required. As a general rule, conventional epoxies are best used for new construction when the majority of the mill scale has been removed and when good workshop through-put is needed. The slower drying / curing but better surface wetting of the epoxy mastic is ideal for maintenance situations when optimum surface preparation cannot be used. However, the best durability comes with a clean surface so whenever possible it is recommended to specify the highest grade of surface preparation.

23. ACKNOWLEDGMENTS

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24. REFERENCES

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25. AUTHOR DETAILS



Geoff White is the Technical Sales Support Manager for the Jotun International Specification Management group headquartered in Norway.

Geoff has been working in the Protective Coatings Industry since 1980 and holds the following industry recognitions. ACA Coating Inspector #75; ACA Corrosion Technologist #182, NACE Certified Coating Inspector #8427; FROSIO Inspector Level 111 #4911 and SSPC Protective Coating Specialist ID# 2011-023-256