Corrosion Under Insulation Technologies – High performance solutions

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ABSTRACT

It has been recognized by most facility owners that corrosion under insulation is a phenomena which needs special attention during design and construction. If the pipes and vessels are left uncoated or if the wrong type of coating has been applied before the insulation material is wrapped around – the result will often show up in a few year times in form of heavy corrosion under the insulation material or even break down due to leaking pipes or vessels.
Selecting the correct coating to protect the vessel or pipe before insulation can be a challenge especially when we see a lot of new coating technologies reaching the market. This paper will discuss the reason for have different coating technologies available and what to look for when specifying coatings under insulation.

1. INTRODUCTION

Corrosion under insulation (CUI) is defined as a severe localized form of corrosion due to entrapped water under the insulation layer of piping and vessels. CUI is extremely critical since it takes place out of sight and may cause costly unexpected shut downs and accidents. If the cladding is completely tight we will have no water ingress and the problem is solved. In real conditions, however, it is not possible to make the cladding completely tight. Since it is not possible to keep water out of the insulation there is a need for barrier coatings to prevent corrosion under insulation. It is crucial to consider the environment and operating mode of the equipment. As long as the equipment is operating and hot the insulation may stay dry and the environment is not aggressive, but what happens during shutdown periods or in equipment operating in cyclic conditions? There will be a risk of condensation, water under the cladding is never entirely expelled and additional water is drawn in whenever available. Electrolytes concentrate and eventually the insulation becomes saturated. The result is corrosion if the substrate is not properly protected. For more details on the mechanism of CUI see [1].
Other factors like design of the equipment or the insulation material itself and the environment have to be considered. It has to be considered if the insulation material contains salts or other substances which

will speed up corrosion. Also insulation material which to tend to have a capillary action has to be avoided [6].

Since it is not possible to keep water out of the insulation there is a need for barrier coatings to prevent corrosion under insulation.

Various coating technologies and products are available to prevent CUI and the area is evolving with new products entering the market with claims of improved properties in terms of the temperature range they can cover, the protection they offer etc. Such products, of course, have no long track record and we have to rely on accelerated laboratory testing. Although there are some standards or guides to help us specify coatings for CUI (NACE SP 0198-2010 [1], NORSOK M501 ed. 6 [3], and also under NACE a task group; TG 425 is working on the state of art CUI coatings) there is no generally accepted test method and the standards do not agree on what the optimum solution is. A simplified overview of the recommendations from the standards is given in Figure 1. As can be seen there is no consensus on maximum operating temperature for the various coating types. Another problem is that there are no clear definitions of the generic coating types mentioned in the standards. E.g. a large number of different coating formulations are described as “epoxy phenolic” and can be used according to Norsok although they can have very different composition and properties. “Epoxy phenolic” has no generally accepted definition or chemical meaning and in fact virtually all commercially relevant epoxy resins are made by reacting epichlorohydrin with a suitable phenol. From a chemical point of view all epoxies are therefore equally “phenolic” and the term does not assure specific properties or high performance.
It is the aim of this paper to investigate the suitability and limitations of various coating technologies and give recommendations for specifications depending on operating parameters.

2. COATINGS FOR CUI PREVENTION

The understanding of how to avoid CUI and the coating products for CUI prevention is an evolving area. The status in 2004 is summarised by Fitzgerald [4] who suggest organic coatings up to around 100°C. for higher temperature other more costly solutions like thermal spray aluminium and Al-foil wrapping is suggested. Since this paper, new coating types (high build silicones) have entered the marked and the use of existing types (epoxy) have expanded to higher temperature. Haraldsen [4] investigated the performance of two such new high build silicones and compared to a “phenolic epoxy” and thermally sprayed aluminium. In this study the two high build silicones provided very little corrosion protection under wet conditions and heating up to 120 °C.
Figure 2 gives a short summary of coating types currently and historically used under insulation. The first group consists of the organic types (epoxy, phenolic epoxy and novolac epoxy). They give excellent protection against water and salts etc., however the disadvantage is that they degrade at moderate temperatures and cannot be used for the hottest areas. Among the second group, the inorganic types, we find the zinc silicates. They resist higher temperature than the organic coatings and can provide excellent corrosion protection. Historically these products have been used on insulated pipes with some success. However their use has also resulted in premature breakdown because they are not suitable for a wet and hot environment. At temperatures above 60 °C the dissolution rate of zinc and zinc oxide becomes very

high and even the polarity between zinc and iron might under some pH conditions switch so iron protects the zinc instead of zinc protecting the iron. This results in rapid break down of the coating system and even galvanic corrosion of the steel. In real life there is often a risk of encountering such conditions e.g. during shutdown periods and the use of zinc silicates is not generally recommended. Among the second group we also have thin film silicones. They have high temperature resistance and do not suffer from the shortcomings of zinc silicates because they do not contain zinc pigment. However, the corrosion protection offered by these coatings is limited due to the low film thickness. Finally we find also high build silicones which is a relatively new class of coatings entering the marked to address the shortcomings of the previously mentioned coating types. They have high temperature resistance and much better anticorrosive performance than thin film silicones. The third group consisting of metallic coatings, thermally sprayed aluminium and zinc, provides excellent anticorrosive performance and is probably the most durable solution. They are also expensive and inconvenient to use – especially in maintenance it may not be realistic to apply these types. This paper will mainly focus on epoxy mastic, novolac epoxy and high build silicones.

3. EXPERIMENTAL SET-UP

3.1 Coating systems

In this paper both organic epoxy and inorganic silicone coatings have been studied. The aim has been to investigate what is the optimum solution at different temperatures.
According to their data sheets the commercial products are described as:

a) Epoxy Mastic: A two-component polyamide adduct cured, high solids, high build epoxy paint.
b) Novolac Epoxy: A two-component, amine adduct cured phenolic epoxy (novolac) coating with very good adhesion and high temperature, water and chemical resistance.
c) High Build Silicone 1: A one component MIO pigmented high build silicone for insulated and none-insulated steel up to 450°C.
d) High Build Silicone 2: A one component MIO pigmented high build silicone for insulated and none-insulated steel up to 650°C.
e) Thin Film Silicone: A one component thin film aluminium pigmented silicone coating for use up to 600°C.

Furthermore experimental high build silicones were tested. They were all one component high build silicones pigmented with MIO, Aluminium flakes and other pigments and fillers in various amounts.

All coatings were applied by airless spray on steel panels prepared to Sa 2½ by abrasive grit blasting unless otherwise stated. Specification was 2 or 3x100µm dry film thickness for epoxy coatings. For High build silicone the DFT were 2 or 3x 150µ and for thin film silicones 3x 25µ. All panels were cured at ambient conditions for minimum 1 week unless otherwise stated.

3.2 Experimental procedures

A number of experimental techniques were used to investigate and compare the temperature resistance and corrosion protection offered by the coatings.

1) Crack resistance – dry exposure in oven at constant temperature. The coated panels were exposed for 24 hours at temperatures from 300°C until 650°C in increments of 50°C. After each heating period the panels were inspected under microscope for cracking, delamination and blistering before being put back in the oven for the next heating period.

2) Salt spray exposure for 12 weeks according to ISO 7253.

3) Cyclic CUI test. The complete test consists of 80 cycles with each cycle comprising:

- 16 hours dry heating in oven at 210 °C.
- Quench cooled in cold water. The hot panels are submerged in cold tap water directly from the oven before cooling (max 30 s transfer time).
- 8 hours immersion in boiling freshwater.

4) Combined Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) on a free paint film

5) Cyclic heating/immersion on flat panels with an artificial damage was made down through the coating. One cycle comprised heating the panels in an oven at constant temp (150, 200, or 250 °C) for 6 hours, then cooling down in air and immersed for the rest of the day in 1% NaCl solution – all repeated for 21 days.

6) Modified Houston pipe test which consisted of exposing pieces of coated and insulated pipe to cyclic immersion and dry out conditions at elevated temperature, see Figure 3. Two 2 mm wide scribes were made through the coating along the length of the pipes. The exposure cycle consisted of heating on a hot plate for 8 hours (standing in vertical position), followed by cooling down to below 50 °C before a salt solution was poured slowly into the insulation. Then the pipe was placed horizontally (to make sure that the water concentration was the same throughout the pipe length) for another 14 hours and finally set back on the hot plate. The procedure was repeated 21 times for a total of 3 weeks of exposure. The pipes are evaluated after the test since the insulation has to be removed. The advantage of this setup is that a coating can be tested at wide temperature range in one exposure. A number of thermocouples were inserted into the insulation to measure the steel temperature along the pipe. This is used to make a correlation between temperature and location on the pipe. See Figure 4.

4. RESULTS & DISCUSSION

4.1 Thin film silicone

Traditional thin film silicones are generally not considered as suitable for CUI protection due to limited corrosion protection and this is confirmed by the results from salt spray testing and cyclic CUI exposure shown in Figure 5. Even short term exposure to salt spray or the cyclic CUI test leads to general breakdown of the system and corrosion. This can be explained by the inadequate barrier properties offered by the rather low film thickness that can be obtained even with a 3 layer specification. More layers to build up a thicker film would possibly improve the performance but this is not a practical solution. The newer high build silicones were developed to address this.

4.2 Max temp of high build silicones

A number of experimental high build formulations were formulated and screened to identify the best by exposure to dry heat in oven. The two commercial High Build Silicone 1 and 2 were used as references. Several of the experimental formulations cracked at moderate temperatures (300 - 500°C) while a few showed no crack up to 600 °C and only minor cracks at 650°C. See Figure 6. This is better than the two commercial high build silicone products. High Build Silicone 1 cracked already at 300 °C and Build Silicone 2 cracked at 400 °C.
Although all formulations can be characterised as high build silicone it is clear that the details of the formulation has a strong influence on the heat resistance. Products with similar generic description may perform quite differently and it is important to use products with proven performance.

In all cases the heat exposure resulted in some degree of colour changes due to oxidation of iron oxides in the formulations. This is only a cosmetic effect and does not affect the overall performance.

The exposure to dry heat showed that the best experimental formulations have the better temperature resistance as the commercial products and that the commercial products actually cracks before their rated max temperatures.

4.3 Corrosion protection of high build silicones and novolac epoxy

The best experimental formulation was selected for further testing. Resistance to the stresses under insulation were simulated in the cyclic CUI test and some results are shown in Figure 7. The coatings were tested in 3x150µm because the tendency to cracking is increased by high film thickness. Both the Experimental High Build Silicone and High Build Silicone 1 perform well and show no cracking or other degradation while High Build Silicone 2 is cracking severely. In real life conditions this coating would not offer much corrosion protection during periods of shut down.
The effect of film thickness was further investigated for the Experimental High Build Silicone and the results in Figure 8 show a strong influence of total film thickness. The system with 2x150µ performs much better than the system with 150µm but still show some corrosion after 50 cycles. Only the systems with higher total film thickness (3x150µ and 2x300µm) showed no corrosion after 80 cycles.
The protection provided by intact coating films were then investigated by exposure to salt spray. Panels cured at ambient conditions as well as after heat exposure were tested and compared to the Novolac Epoxy. See Figure 9 - Figure 11. The novolac epoxy performed excellent with no rust after 12 weeks even at 100µm film thickness while the high build silicones need much higher film thickness and even at 450 µm corrosion occurs after 12 weeks when cured at ambient temperature. It is interesting to note that the Experimental High Build Silicone provides much improved corrosion protection after exposure to 650 °C. It is evident that further curing reactions takes place during heating whereby the barrier properties are increased and corrosion protection improved.

High build silicones resist high temperature better than novolac epoxies. On the other hand they provide lower barrier properties and corrosion protection. This corrosion resistance can be improved by building up higher film thickness without jeopardising the crack resistances.

4.4 Max temp of epoxies

Epoxy (in particular Novolac Epoxy) provides better corrosion protection than high build silicones as shown in the previous section. Epoxy coatings are therefore the preferred solution for CUI when possible. However due to their organic nature the temperature resistance is lower and it is crucial to establish the practical max operating temperature for these coatings.

The cyclic heating/immersion test was used to investigate the maximum temperature limit for the full coating systems. The failure mode was mainly cracking – no real corrosion creep from the scribe was observed. The results in

Table 1 show that the upper temperature limit of epoxy novolac is between 200 and 250 °C and for the epoxy mastic between 150 and 200 °C. No difference was seen between systems with 2x100µm and systems with 3x100µm. A few panels were applied by brush to compare with the spray applied panels. It was found that this lowers the crack resistance leading to cracking at lower temperature than for spray applied. Cracks appear in the direction of the brush strokes as shown on Figure 12.

These findings were supplemented by the modified Houston pipe test. Failure is cracking and delamination (most severe at the bottom of the pipe where the temperature has been highest). Figure 13 and Figure 14 show examples of the Novolac Epoxy and the Epoxy Mastic after exposure.

With the correlation between pipe length and temperature it was possible to identify the temperature at which failure (delamination and cracking) sets in – see Figure 15. It is clear that the novolac epoxy can reach a higher temperature before cracking and delamination is observed, compared to the epoxy mastic. The results also indicate that a high film thickness is not an advantage. Films with 2x100µm resist slightly higher temperature than films with 3x100µm.

Some degree of surface colour change (darkening) was also observed for both epoxies after heating and this tendency is stronger at higher temperature. This is a cosmetic surface phenomenon and does not seem to affect the bulk properties of the coating systems as can be seen on Figure 16.

The higher temperature resistance of the novolac epoxy compared to the Epoxy Mastic is probably due higher cross link density and lower content of non-reactive components. Such non-reactive components may evaporate from the film during the heating leading to shrinkage, internal stress and eventually cracking. The difference in mass loss during heating was investigated with thermo gravimetric analysis (see Figure 17). For both epoxies the mass loss is negligible up to 150 °C and even at 200 °C it is modest and this mechanism do not seem to be sufficient to explain observed failure of the epoxy mastic at approx. 160 °C.

The results show how Novolac Epoxy and Epoxy Mastic can resist CUI conditions up to approx. 240 °C and 160 respectively under idealised laboratory conditions. For real life application the max temp has to be lower due to variations in film thickness etc. NACE SP 0198-2012 suggests using novolac up to 205 °C and this work confirms that this is a practical upper safe service temp.

5 CONCLUSION

- Thin film silicone paint is not adequate for protection against corrosion under insulation.
- High build silicones can in some cases provide protection up to 650 °C. Performance is improved by heat curing at high temperature.
- Novolac epoxy provides better corrosion protection at low temperature than silicones and should be the preferred solution up to approx. 205 °C.
- Generic descriptions are not enough to guarantee good performance – details of the formulations can result in widely different performance.

    - Good AC property is mainly determined by proper adhesion to the substrate and a non-porous and crack free film.
    - Heat stability of the coating is mainly determined by type of binder, type of pigmentation and film thickness.
- Suggested specifications for different temperature ranges are given in Table 2
- The performance of actual products have to be documented through laboratory tests and fields experience before being specified

6 ACKNOWLEDGEMENTS

Thanks to Yu Jiang for performing much of the experimental work [7]

7 REFERENCES

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8 FIGURES AND TABLES

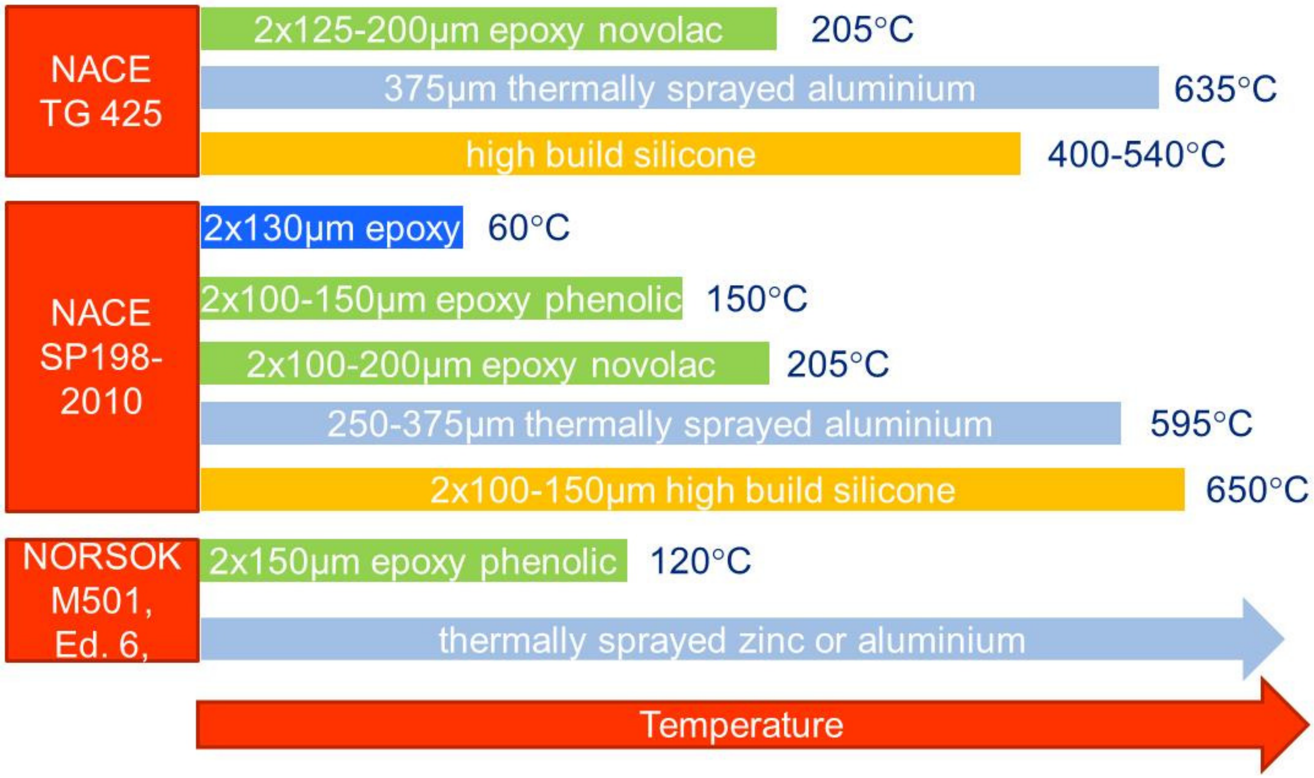
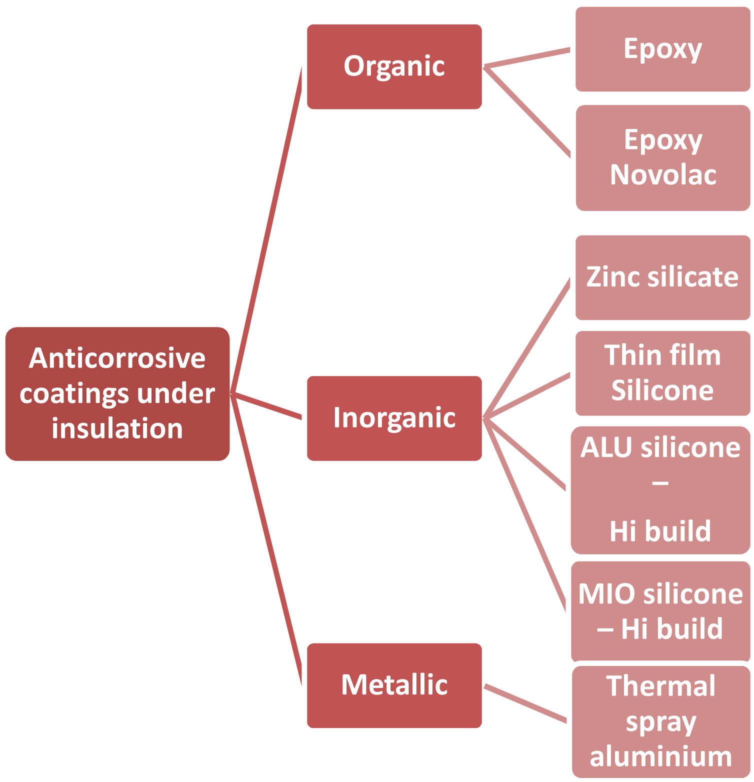


Figure 1: Overview of upper temperature limits for various coating types according to Norsok, NACE SP0198 and NACE TG 425. (Melting points: Zn 420°C, Al 660°C)



Advantages	Disadvantages
Cost Mechanical properties Resistance to water, solvents, & chemicals Corrosion protection Well know and proven technology	Low temperature resistance
Temperature resistance	Poor resistance to warm humid conditions
Temperature resistance	Low corrosion protection
Temperature resistance Better corrosion protection than thin film silicone	Lower corrosion protection than epoxy Emerging technology
High temperature resistance Excellent AC resistance	Cost Application process

Figure 2: Examples of three groups of coatings to be used under insulation: organic, inorganic and metallic.

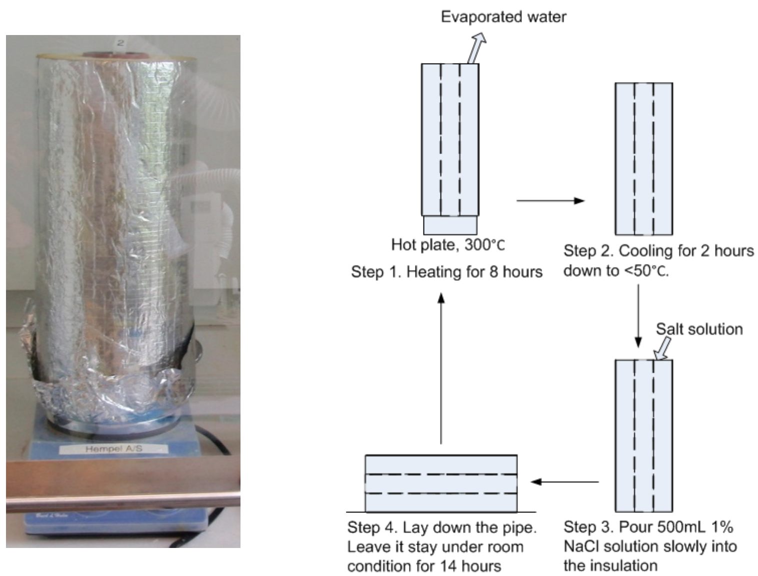


Figure 3: The modified Houston pipe test

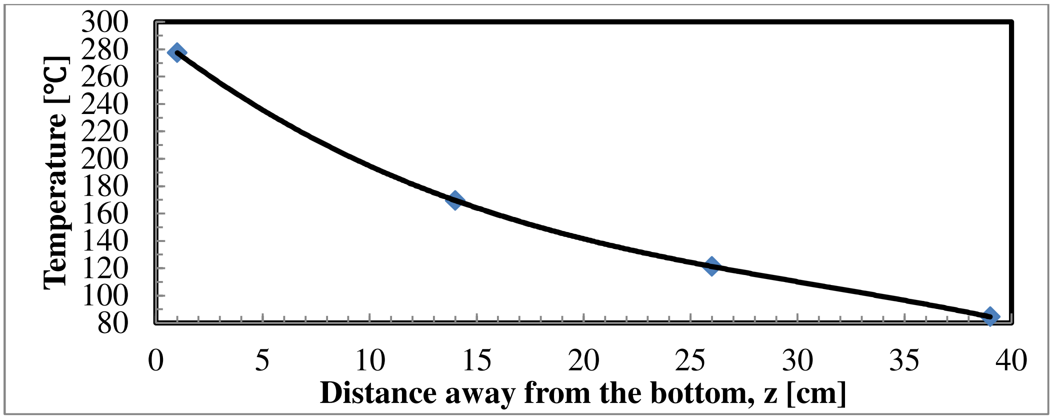
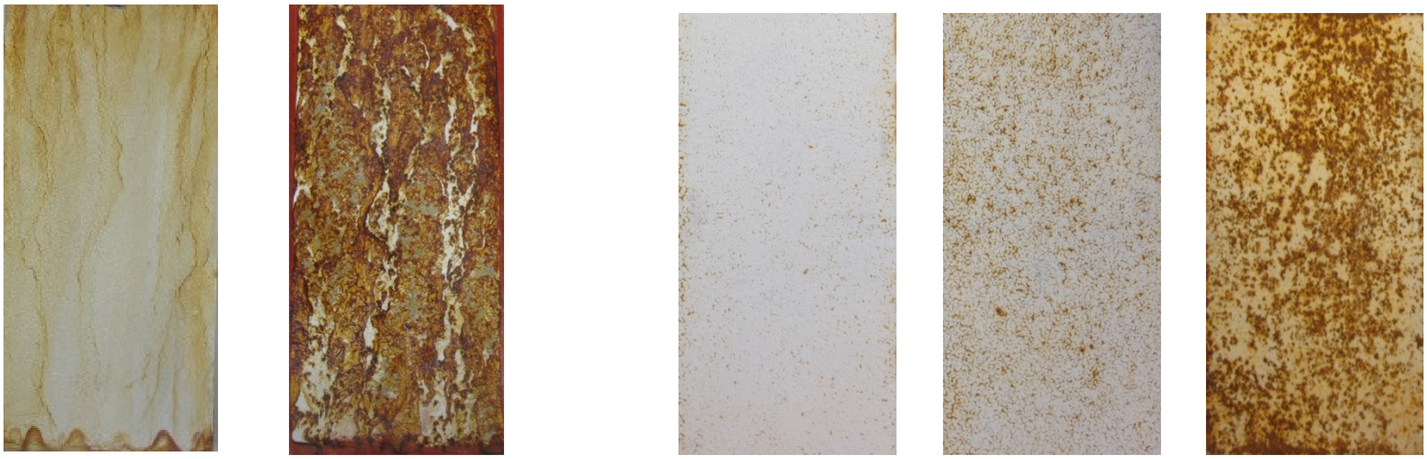


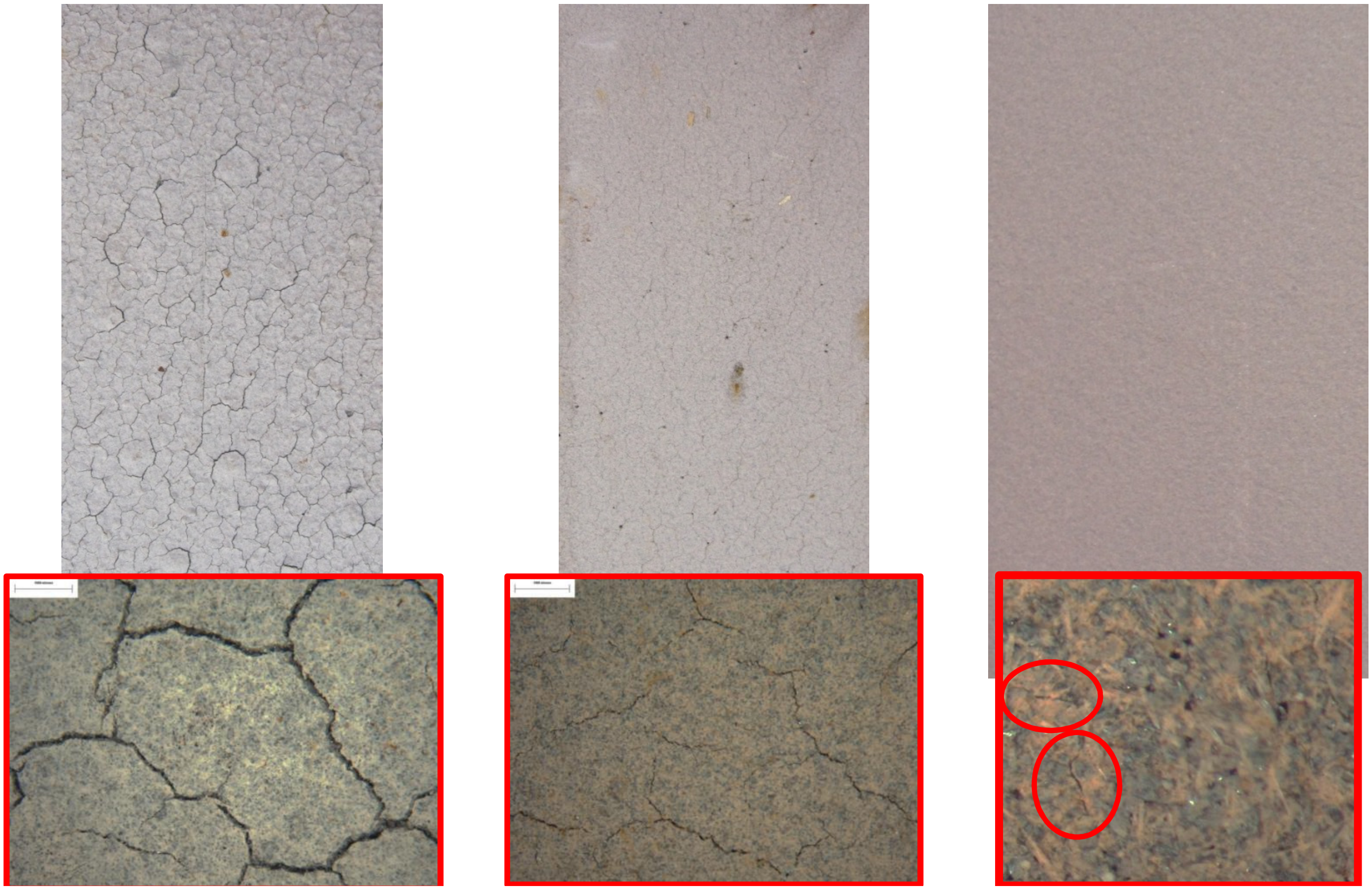
Figure 4: The temperature along the length of the pipe at steady state during the Houston pipe test. The temperature at the bottom of the pipe in direct contact with the hot plate is approx. 290C (z=0cm) dropping to approx. 80 at the top

Salt Spray Test - 720 h exposure **Cyclic CUI test**



<u>**No**</u> heat exposure Exposed to 650 °C 18 cycles 34 cycles 60 cycles

Figure 5: Test of corrosion protection offered by a convensional Thin Film Silicone specification 3 x 25 µm. The heating to 650 °C caused widespread micro cracking with subsequent corrosion in the salt spray exposure.



High Build Silicone 1
First sign of cracking 300°C

High Build Silicone 2
First sign of cracking 400°C

Experimental High Build Silicone
First sign of cracking 650°C

Figure 6: Cracks formed after heating 3 high build silicones (1 x 150 µm) to 650 °C.

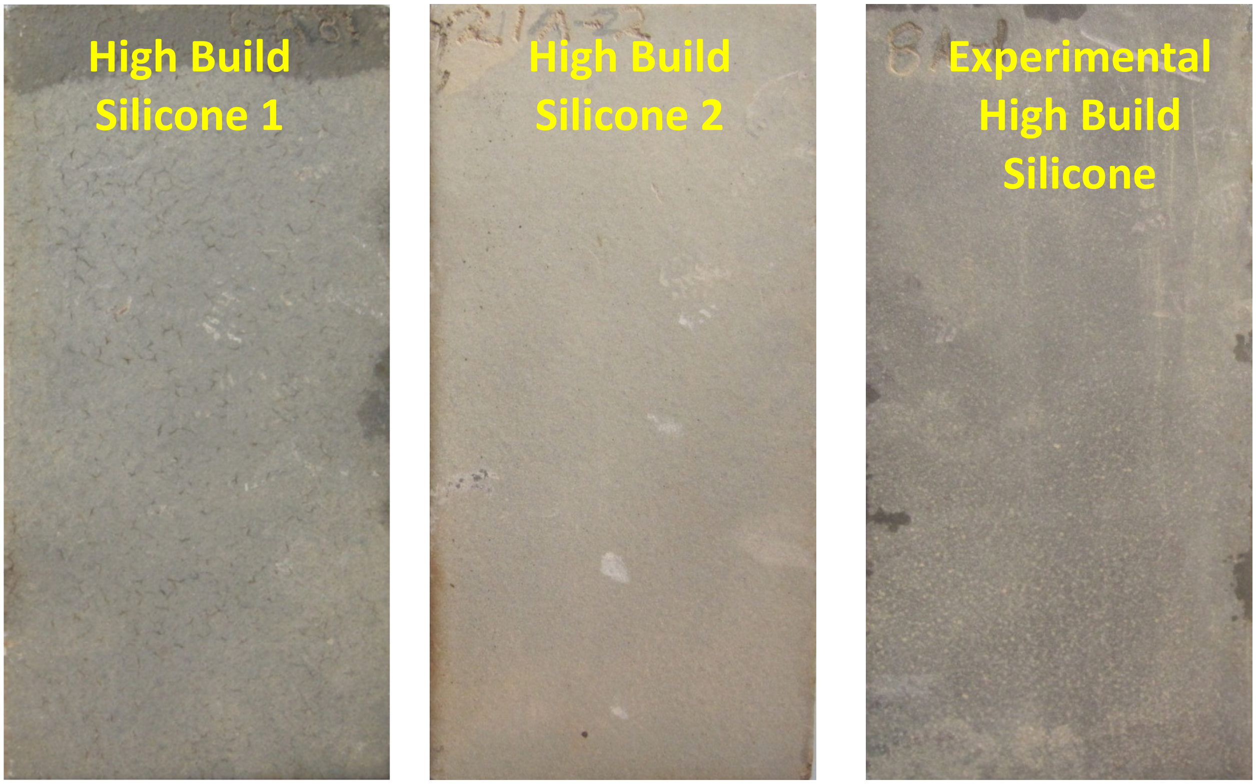


Figure 7: Example of performance of three high build silicones (3x150µm) after exposure to 80 cycles of the cyclic CUI test. High Build Silicone 1 shows general cracking while no signs of degradation are found on the other two.

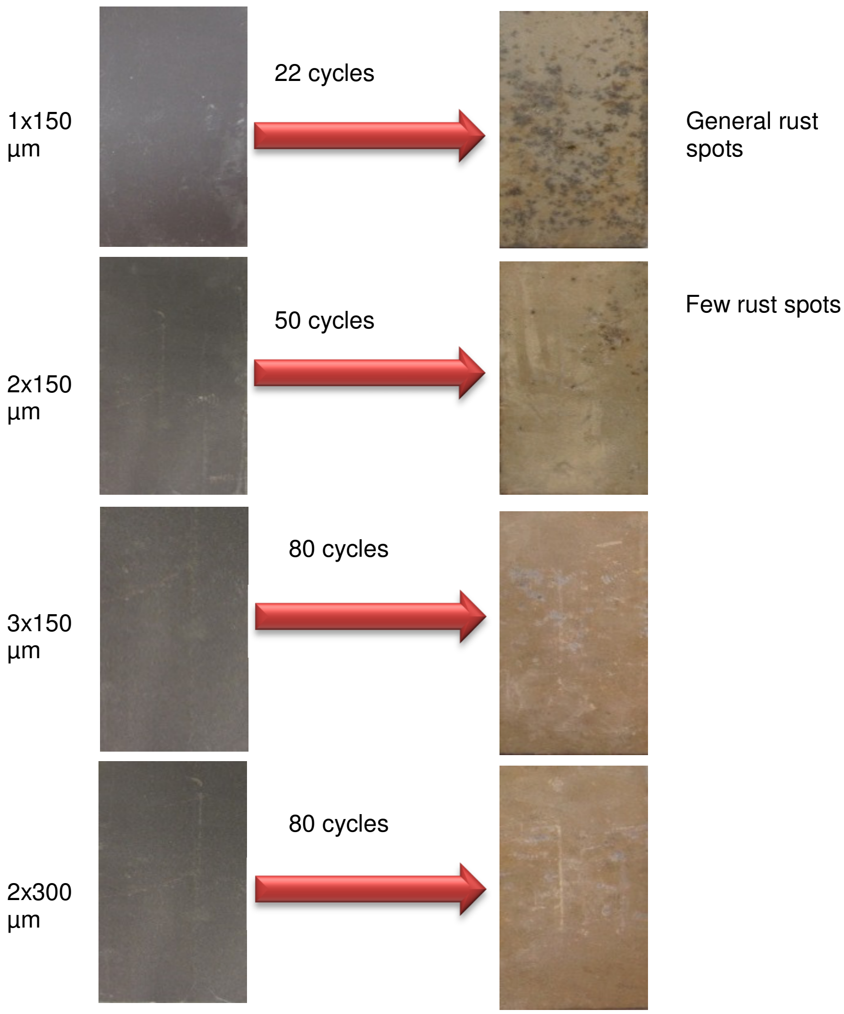


Figure 8: Experimental High Build Silicone after exposure to cyclic CUI test. None of the systems cracked but rust spots can be observed at lower film thickness. No rust is seen at a film thickness higher than 2x150 µm.

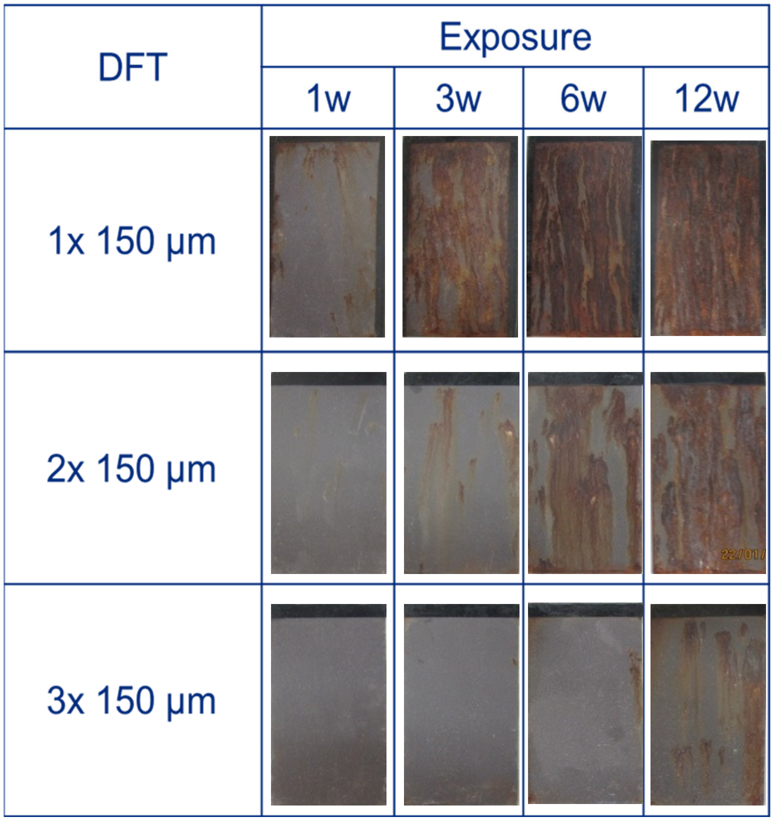


Figure 9: Experimental High Build Silicone exposed to salt spray (ambient curing).

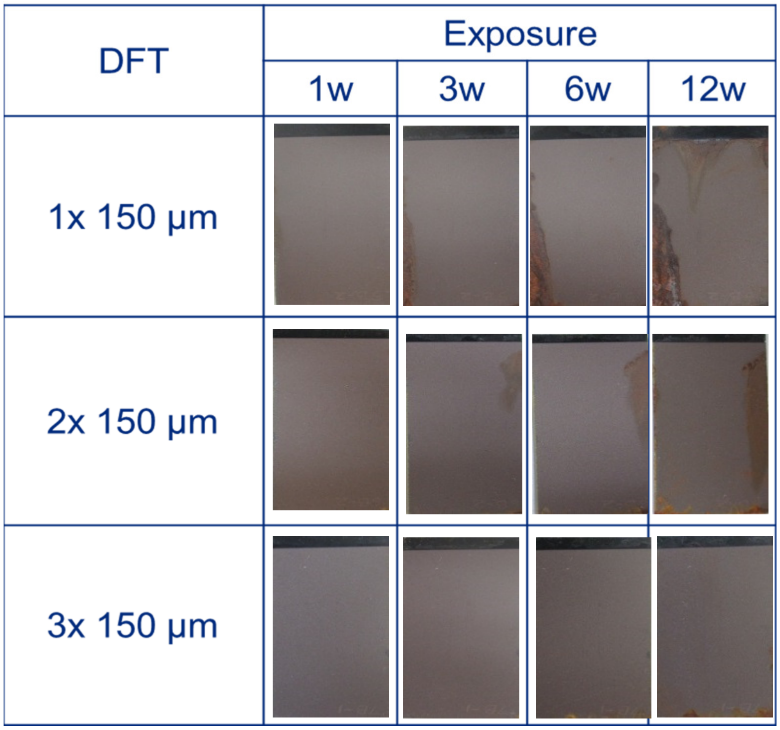


Figure 10: Experimental High Build Silicone exposed to salt spray (heat cured at 650 °C).

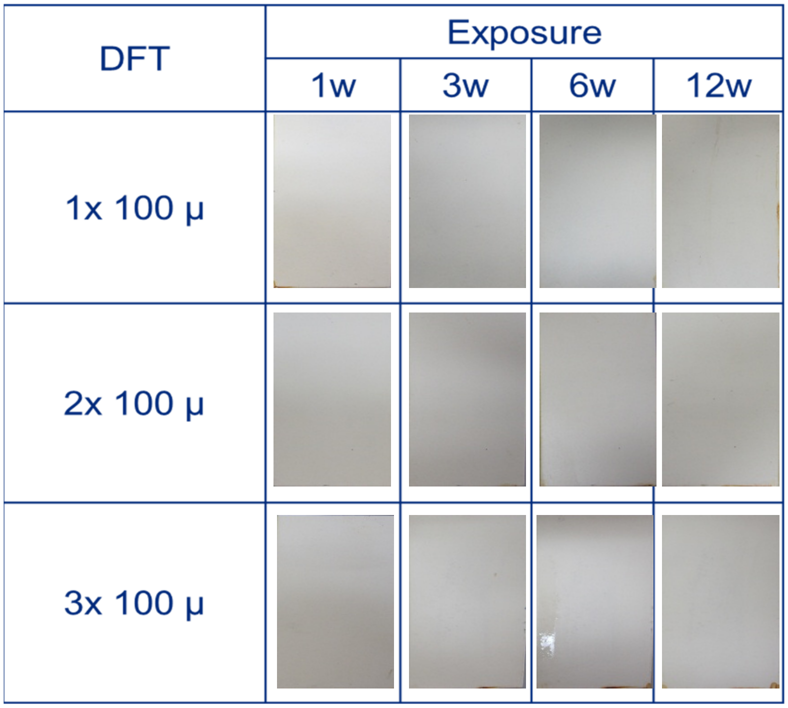


Figure 11: Novolac Epoxy exposed to salt spray – no rust.

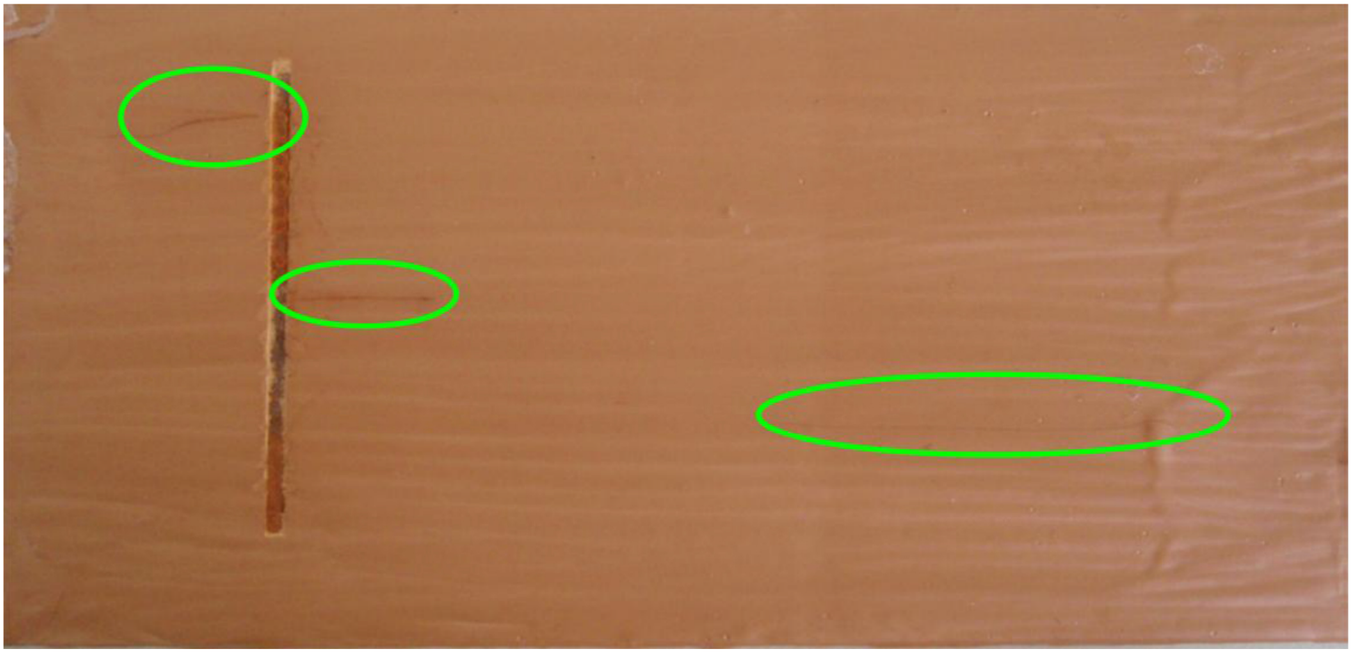


Figure 12: Panel with 3 layers of Novolac Epoxy applied by brush after 4 days exposure to the cyclic heating/immersion at 200 °C.

Epoxy Novolac 3×100µm

Epoxy Novolac 2×100µm

Epoxy Mastic 2×100µm

Epoxy Mastic 3×100µm

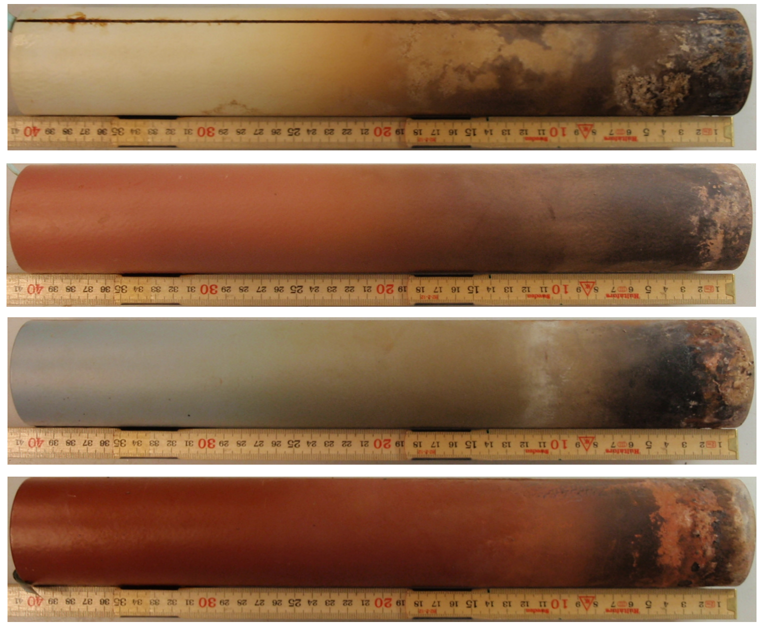


Figure 13: The pipes after exposure in the Houston modified pipe test

Figure 14: A pipe with 3x100 µm Epoxy Mastic after exposure in the modified Houston piep test. The delamination from the scribe was determined with the tip of a knife to extend to approx. 17.5 cm from the end of the pipe corresponding to a temperature of 153 °C.

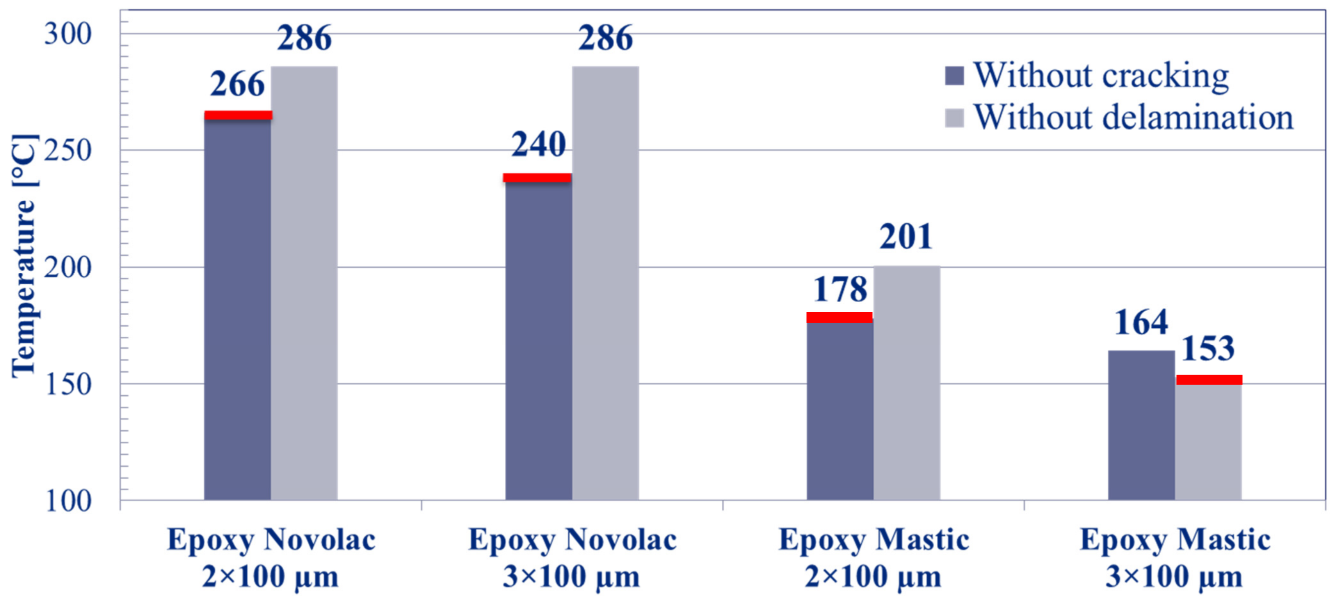


Figure 15: It is clear that the novolac epoxy can reach a higher temperature before cracking and delamination is observed compared to epoxy mastic. The plot here also indicates that a high film thickness is not an advantage.

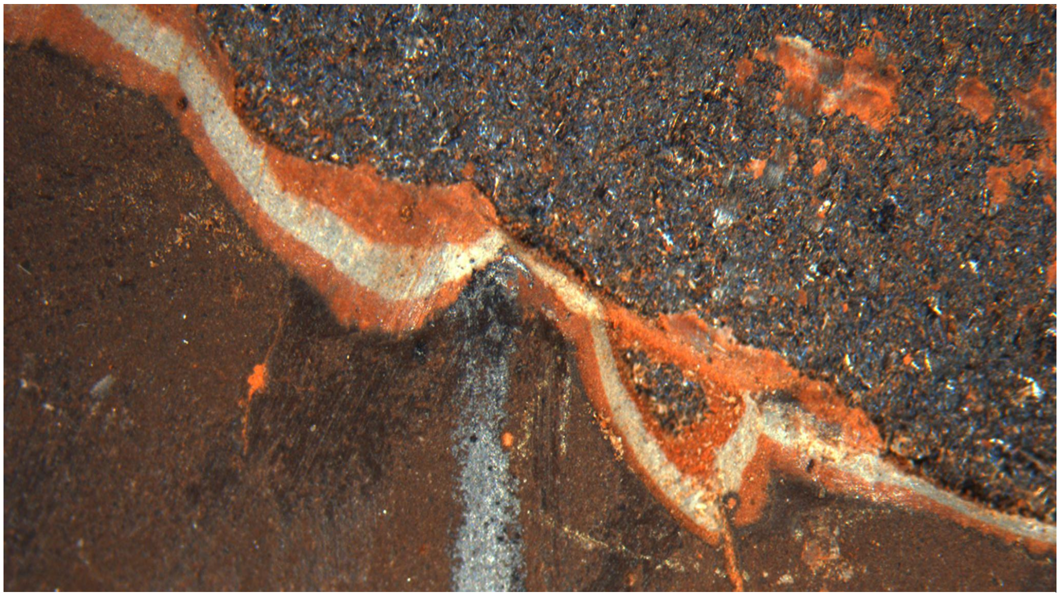


Figure 16: Close up of 3 layer coating system after exposure to heat. The surface shows darkening whereas the deeper sections have retained the original colour.

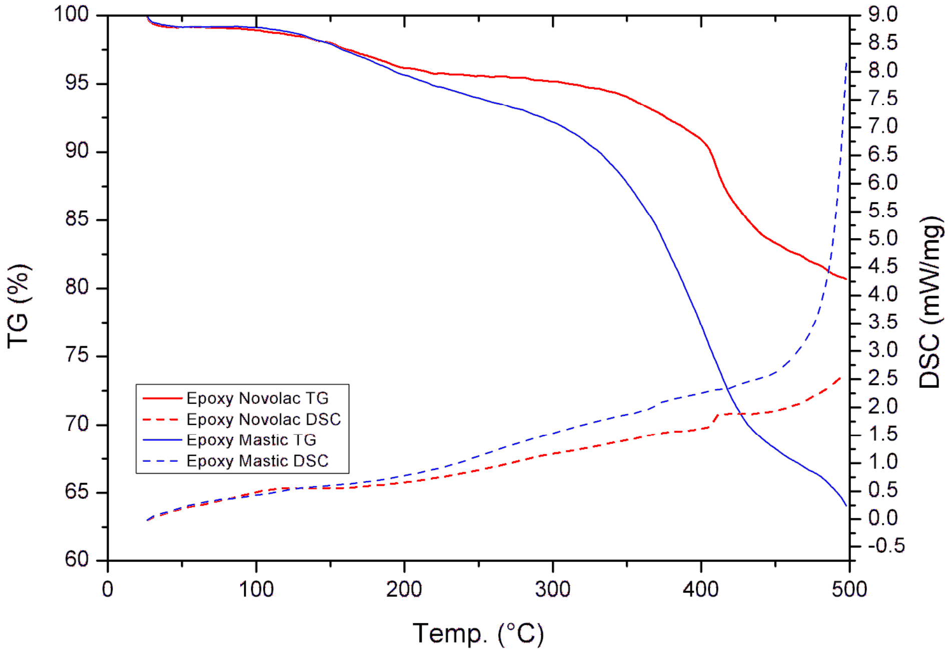


Figure 17: Simultaneous TGA and DSC analysis performed on a free film. The mass loss seen is associated with water evaporation (up to about 150 to 200 °C) followed by binder degradation.

Table 1: Results from exposure of epoxies to cyclic heating/immersion.

Exposure time for cracking to occur		
Heating temp.	**Epoxy Novolac**	**Epoxy Mastic**
150°C	-	-
200°C	-	20 d
250°C	9 d	5 d

Table 2: Suggested recommended specifications for various temperature ranges**.**

Temperature range	Binder type	Comment
-60 °C	2x150µm epoxy	May be used but Novolac epoxy would be more durable
-160 °C	2x150µm novolac epoxy	Complies to Norsok M501 ed. 6 System 2A
160-205 °C	2x100µm novolac epoxy	
205 °C -600 °C	2x150µm high build silicone	