

## **TESTING OF OFFSHORE SYSTEMS – IS THERE A REALISTIC TESTING SCENARIO OR IS THERE STILL WORK TO BE DONE**

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### **ABSTRACT**

Although in the 1980's a number of oil companies requested prequalification testing (primarily in the USA), many did not but relied solely on advice from paint companies. Eventually NACE produced TM 0184 but complexity of test equipment meant little take up. However, premature breakdown and systems failures have led to a major resurgence in activity in both Oil Companies and paint suppliers over the past 10 years, so that there now exists around the world a whole series of various testing scenarios.

This paper will review these tests, covering ISO 20340 along with others, and consider how the recently published NACE Offshore Coating Test Methods could become a 'Universal' standard by further developing the duplex testing theme of corrosion testing and film stability/stress (cracking) testing.

Key Words: Failure; Test methods; Film stability.

### **INTRODUCTION**

Correlation between real life performance and laboratory accelerated testing procedures is a general requirement in the evaluation of any material. Unfortunately, in the Protective Coatings Industry a reliable method does not really exist. Most coatings manufacturers release products to the market based on field trialling, accelerated laboratory performance tests, and a range of "fitness for purpose" tests generally based upon experience. There is no published or documented proven procedure.

## BACKGROUND

Recent years have seen extensive work being undertaken in the development of various cyclic test methods, which appear to give much better ranking of coatings systems when compared to simple constant wetness tests in electrolytes such as salt spray. These tests have largely been driven by the Offshore and Bridge industries, in both areas the consequences of having premature coating failure are major and repair extremely expensive.

In this paper accelerated testing for offshore systems only shall be considered, this has received considerable effort since the early 1980's, and in the past few years an increasing amount of work has been put into this area, by all involved.

As mentioned earlier, traditional testing in simple salt spray chambers has now been largely discredited, with current thinking being focused on the use of cyclic corrosion testing, i.e. an alternating exposure to electrolyte and to some type of weathering. Study of ASTM B117 results, in terms of both ranking of system's performance compared with that obtained on external exposure and analysis of corrosion degradation products, shows no correlation with what happens in practice. Performance assessment is made on the basis of rust creepage measurement from defect introduced into the coating ("scribe"). This variation of exposure conditions between wet and dry, as well as introducing U.V. degradation, causes more stresses on the film and has been shown to give corrosion products more similar to those found in practice in both chemical composition and appearance.

Most of the early work in this area of cyclic testing was done for the Gulf of Mexico, most specifically by Lee Bone, with cyclic weathering and corrosion and Gulf with wet and dry, immersion and dry-out cycling.

This test became the NACE TM 0184, which surprisingly did not find widespread acceptance. It was used by Arco for around 20 years with claimed good correlation with practice. Perhaps one problem was that the test method gave a number of possible variants of testing scenarios, always likely to cause a problem with acceptance by structure owners because of uncertainty of equivalence.

There was also probably another reason, financial. At this time, many systems used offshore had considerable track record and there was general reluctance of all concerned to invest in what was relatively expensive testing compared to the straightforward traditional methods such as salt spray (in cyclic tests panels generally have to be moved from one piece of equipment to another at regular intervals).

It should be realized that many systems which were used around the world during the 1960's, 1970's, and even until the late 1980's, had very little accelerated testing. At this time, in most cases, 1000-2000 hours salt spray, immersion and external exposure were the norm. The question as to why systems performed so well then needs to be answered.

The reason lies in the types of paint technology utilized and the relative absence of environmental and health and safety restrictions. Most of the coatings applied were lowly stressed thermoplastic coatings or low solids epoxies, again with inherently low stresses. These materials generally had extensive use in other areas before being used offshore.

Thus the scenario in the early 1990's was that some companies in both the USA and Europe undertook some type of test program, however, these were not widely recognized and often there tended to be no formal route for approval of new systems.

## CURRENT POSITION

### Norsok

The current position regarding testing probably could be considered to start with the work done in Norway to produce the Norsok MCR 501 Standard. This work was initiated by the Norwegian Government because of a number of expensive failures offshore, not just with coatings but in a number of areas which clearly demanded prequalification and overall tighter control. For coatings an extensive program was put together to evaluate the various testing options available, directed by a group consisting of Oil Companies, Offshore Fabricators, Paint Manufacturers and Applicators. The scientific program was undertaken by a testing and consultancy group who were part of the University of Trondheim. A number of cyclic tests were evaluated, including NACE TM 0184, ASTM D5894, ASTM G85, the Volvo test and others, as well as ISO 7253 Salt Spray and ISO 6270 Condensation. Panels were exposed at a coastal site and on an offshore platform for correlation purposes (around 70%). Following this program of work, it was concluded that the TM 0184 type cycle gave best correlation to exterior exposure and this was selected for the Norsok test, but focusing specifically on cycling between ISO 7253 Salt Spray, ASTM G23 QUV-A with a dry out period. Initially ISO 7253 Salt Spray and ISO 6270 Condensation formed part of the test but were later dropped as the cyclic test was considered to be the most relevant.

In France an AFNOR NFG 34-600 Standard was used by oil companies, along with other organizations, but although a useful series of cycles has generally been considered too complex and difficult to run. It should be pointed out that the Norsok test especially is purely on performance of the applied film, it gives no indication as to the practicalities of the coating in terms of application or overall fitness for purpose.

### ISO 20340

For general structural steel ISO 12944 – Corrosion Protection of Steel Structures by Protective Paint Systems – was published in 1998, and it was very quickly realized that the section referring to systems in a marine environment gave totally inadequate tests for lifetime expected, e.g. 1440 hours ISO 7253 Salt Spray, 1mm rust creepage, time to first major maintenance greater than 15 years.

Thus a new ISO Standard for Offshore Structures was initiated (by France), currently in draft for as ISO 20340 – Performance Related Requirements for Protective Paint Systems for Offshore and Related Structures. The standard has unfortunately ended up as something of a compromise between the French AFNOR (NFT 34-600) and Norsok Standards, panels having to be changed from standard size and each incorporating two scribes of different dimensions, and having different suggested acceptance criteria. One useful feature to come out of this standard was to include the freeze cycle at  $-20^{\circ}\text{C}$  from NFT 34-600, although only optional it is the default. This is extremely useful for introducing further stresses on to the coating and, in my opinion, is an accelerated test should not be optional but compulsory.

Significantly different results can be obtained by utilizing the freeze cycle when compared to the non-freeze cycle (which is basically the standard Norsok test). This is shown in Figure 1.

The above results, utilizing the freeze cycle as part of ISO 20340, give results much more typical of those seen in practice or external exposure testing. No freeze in the cycle, i.e. Norsok MCR-501 test cycle, gives results not typical of those seen in practice and helps given an explanation as to why problems can be seen in the field with system which have performed well in prequalification testing.

The use of a stripe of weld rather than a scribe again reproduces practice and is arguably more useful when assessing the performance of coatings for use and power disced welds.

It is interesting to consider the effect of freeze cycle on simple barrier coat systems as compared to zinc rich primed systems. The freeze cycle basically doubles the underfilm creep of the high solids hydrocarbon modified epoxy giving results much more similar to those seen on severe coastal exposure for 3 years, and to those seen offshore, whereas on the zinc rich primed systems the freeze has no affect and performance is as seen in practice. This is shown in Figures 2 and 3 above.

Although the Draft ISO 20340 Standard does mention application, it is not rigorous in this area, and again largely avoids practicalities.

All of the test methods mentioned to date focus on “performance criteria” and this is totally determined by rust creepage from the scribe (chalked excepted). The pass/fail criteria for a coating system is thus normally determined by the measurement of this creepage. Ideally, pass/fail would be by comparison to a standard system tested at the same time – reproducibility of these test methods is not great, however, the extra cost and choice and availability of suitable materials to an Independent test laboratory prevents this from being used, although individual Oil Companies have effectively used this approach in the past.

Assessment of corrosion at the scribe is made by removing all loose/corroded areas back to clean bright steel, then measuring the rust creepage at a number of predetermined points, and averaging to obtain a final figure. Selection of these measurement points can influence the final figure, especially relevant when 0.1mm can be the difference between passing and failing. In the past, assessment of the total corroded area has been a method of evaluation, probably a better approach, especially with work currently being undertaken which would enable this to be done from digital photographs.

## **NACE**

A somewhat different approach has been adopted by Shell, and subsequently NACE in the development of test methods for offshore systems. In this instance, offshore inspection was undertaken, and root cause analysis done for the various modes of failure. (Unfortunately, this was just done in the Gulf of Mexico and it would be extremely useful to undertake the same exercise in other regions.) This has led to a set of tests which can be used for atmospheric zone new construction, maintenance, water ballast areas new construction and maintenance, submerged areas new construction.

The idea of having a series of tests which include both performance related and those which can be categorized as fitness for purpose is correct and is, in many ways, the route followed by most paint manufacturers in their own development. Some of the tests, such as Taber abrasion, are of debatable use.

Tables 1, 2, 3 give details of the individual tests used, and Table 4 summarizes the packages of tests used for discreet areas.

In this instance the key anti-corrosive cyclic test used is a variant of ASTM D5894 with the specified electrolyte solution replaced by sea water. This drops the number of changes of panel positions to once a week rather than twice, and also does not have a full dry out or freeze cycle. Generally the test gives slightly less corrosion around the scribe than ISO 20340 but in NACE this single test is not the sole basis of decision on performance.

There are a number of potential areas of improvement, especially of concern might be:-

- Length of time for corrosion test
- Ballast cycle test
- No thick film cracking for atmospheric zone

However, real comment cannot be made until more substantial test data has been collected for all of the tests, many of which have very limited data at the moment, and some have probably not actually been run outside of the original exploratory work undertaken as the basis for the testing. The approach is without doubt the correct way forward, and within a few years the correct balance of tests will have evolved.

Even though the NACE approach gives a better potential assessment of performance and fitness for purpose of offshore systems, it is still not all encompassing. Formulators are still responsible for a whole range of issues regarding practical application, this standard really focusing on the cured film.

Typical areas needing to be covered are:-

- Overcoating in various environmental conditions
- Cure in poor ventilation
- Effect of over-application on other properties

Going forward it is probably worth considering mode of failure and long term coating performance in line with how formulations are likely to develop.

There are a number of external drivers influencing coating formulations:-

- VOC Legislation
  - Move to higher solids coatings
    - Less control of dry film thickness, more likely to over-apply.
    - Use of lower molecular weight polymers, increased embrittlement.
    - More potential use of external diluents/flexibilizers – film stability.
- Health and Safety Legislation
  - Restriction on materials available.
  - Potential inferior properties.
- Cost
  - Still no real cost/performance relationship.

Looking at the above and considering the testing scenario already in place, where is there a weakness?

Certainly no coatings company should market a coating on the basis of 12 weeks testing, either accelerated corrosion or immersion, but in terms of rejecting poor systems this could probably be sufficient. On internal testing it would be hoped that decisions would always be based upon a raft of accelerated corrosion tests, and an overall judgment made.

For accelerated corrosion testing there are a number of tests available, none totally ideal but most of the cyclic tests moving in the right direction. What has been of concern is that results obtained from cyclic testing for zinc primed systems tend to give good correlation with panels exposed in aggressive coastal marine environments, non-zinc systems appear to perform much better on accelerated testing than they do outside. Indications are that the freeze cycle in ISO 20340 may create more realistic results here but further investigation is needed.

In practice, in almost all situations, whether atmospheric exposure or immersion conditions, it is not normal to see straightforward corrosion breakdown even after prolonged exposure periods (except in areas where film has been incorrectly applied or specified and is too thin).

More common in the atmospheric zone is to see breakdown on sharp edges, around mouse holes, on welds etc. Welds are probably the most common area, often they are not blasted, and mechanical preparation gives polished rather than roughened surfaces, additional stripe coats increase overall film dry film thickness then poor adhesion and high film thickness can give cracking over time. Care needs to be taken with high solids materials that viscosity has not been reduced by non-reactive diluents such as benzyl alcohol, or low molecular weight plasticisers such as various phthalates, which tend to be transient in the coating. In immersed areas, welds can again be a problem area, and on structures such as water ballast tanks on FPSOs dry film thickness can be extremely high. The likelihood of any failure on any flat areas is extremely low, however, on welds many problems have been observed with non-dimensionally stable coatings.

This observed phenomena of cracking the points at the other half of the performance testing equation, we have a corrosion test (not ideal but workable) but now need a resistance to cracking test, or a test to evaluate whether a system is prone to cracking. Some effort has been made to do this in the new NACE tests but it is doubtful whether these tests as they stand are fully adequate as:-

- they do not address over-thickness in all circumstances;
- do not test on welds;
- do not test on power disced surfaces.

What parameters are needed in a cracking test?

- Substrate - Grit blasted, power tool cleaned
- Dimensions - Welds, edges, corners
- Thickness - Recommended, 2 x dry film thickness, 3 x dry film thickness

Variants then need to be stressed.

A -30°C/60°C cycle as in NACE is good, but can be improved by a water immersion cycle.

Higher temperatures could be relevant for water ballast tanks on FPSOs.

This type of testing and cycling has enabled various coating types to be differentiated and to reproduce some of the efforts seen in practice, e.g. pure epoxy versus hydrocarbon epoxy water ballast coatings.

In conjunction with what could be described as visual tests, it becomes useful to try to correlate what is happening in the film. Simple open circuit potential measurements on zinc primers is a good way to examine the effectiveness of these materials, and increasing levels of work with E.I.S. are showing that the degradation of a coating in an aggressive environment can be followed electrically.

Figures 4, 5, and 6 show the use of open circuit potential measurements to differentiate between zinc primers and illustrate that performance can depend upon other factors than simple zinc level.

Similarly, it is useful to attempt to correlate the internal stress in a coating to its flexibility (not a simple relationship) and to any tendency to crack on thermal cycling or stressing in other ways. Testing and results shown in Figures 7, 8 and 9.

These results can be directly related back to flexibility of the coatings and to reported performance in the field.

### **CONCLUSION**

Much progress has been made in testing of offshore paint systems in the past 10 years, but more work is needed to understand what is happening in the film and give us the confidence to correlate the laboratory accelerated test to the field service life.

The new NACE Standards are a move in the right direction but we must continue to work on them and improve them. We need to be thinking now of new test methods, and modification of those existing, which will give better correlation to service performance.

**TABLE 1  
NACE TG260 TEST METHODS AND SUGGESTED ACCEPTANCE CRITERIA FOR  
OFFSHORE ATMOSPHERIC AND SPLASHZONE MAINTENANCE COATINGS**

Test Type	Standard	Duration	Recommended Pass Criteria
Cyclic Corrosion (Rust Creepage)	Modified ASTM D5894 Synthetic Sea Water	12 weeks	<3mm creepage non zinc <1mm creepage zinc
Cyclic Corrosion (Residual Salt Rust Creepage)	Modified ASTM D5894 Synthetic Sea Water	12 weeks	<3mm creepage non zinc <1mm creepage zinc
Edge Retention	N/A	N/A	>0.5
Thermal Cycling	+60°C to -30°C 2 hour cycle	252 cycles	No cracks
Flexibility (60°C ageing 1 week)	Modified ISO 1519 (Fixed Mandrels)	N/A	>1% flexure strain
Impact Resistance	ASTM G14 or D2794	N/A	>3.4 joules
Abrasion Resistance	ASTM D4060 (CS17 Wheels)	N/A	<50µm thickness loss per 1000 cycles
Cyclic Fog/Dry (Splashzone only)	Modified ASTM G85-AS	12 weeks	No pinholes/rust <3mm creepage

**TABLE 2  
NACE TG263 TEST METHODS AND SUGGESTED ACCEPTANCE CRITERIA FOR  
OFFSHORE PLATFORM BALLAST WATER TANKS**

Test Type	Standard	Duration	Recommended Pass Criteria
Cathodic Protection*	Modified ASTM G8 Synthetic Sea Water	12 weeks	<1mm disbondment
Water Immersion at 40°C*	Modified ISO 2812-2 Synthetic Sea Water	12 weeks	No pinholes/rust >3,4 MPa/<1mm disbondment
Dimensional Stability (Free films)	Synthetic Sea Water at 40°C	12 weeks	Within 0.75% change
Ageing Stability	Modified ISO 1519 (Fixed Radii Mandrel Bending) Control & Aged	12 weeks	>50% flexure strain ratio of aged/control
Edge Retention	N/A	N/A	>0.5
Thick Film Cracking	3 x 500µm Synthetic Sea Water at 40°C	12 weeks	No cracks
Hot/Wet Cycling* (FPSOs)	3 hours wet at 23°C 3 hours dry at 60°C	12 weeks	<3mm creep No pinholes/blistering

\*Carried out over “damp” and chloride contaminated steel (10µg/cm<sup>2</sup> soluble salt) for maintenance systems.

**TABLE 3  
NACE TG264 TEST METHODS AND SUGGESTED ACCEPTANCE CRITERIA FOR  
EXTERIOR PROTECTIVE COATINGS FOR SEA WATER IMMERSION SERVICE**

Test Type	Standard	Duration	Recommended Pass Criteria
Cathodic Protection	Modified ASTM G8 Synthetic Sea Water	12 weeks	<1mm disbondment
Water Immersion at 40°C	Modified ISO 2812-2 Synthetic Sea Water	12 weeks	No pinholes/rust >3.4 MPa/<1mm disbondment
Dimension Stability (Free films)	Synthetic Sea Water at 40°C	12 weeks	Within ± 0.75% change
Ageing Stability (Flexibility)	Modified ISO 1519 (Fixed Mandrels) Control & Aged	12 weeks	>50% flexure strain ratio of aged/control
Edge Retention	N/A	N/A	>0.5





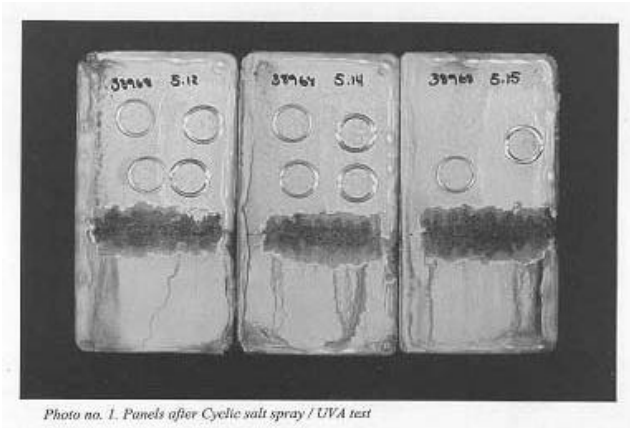
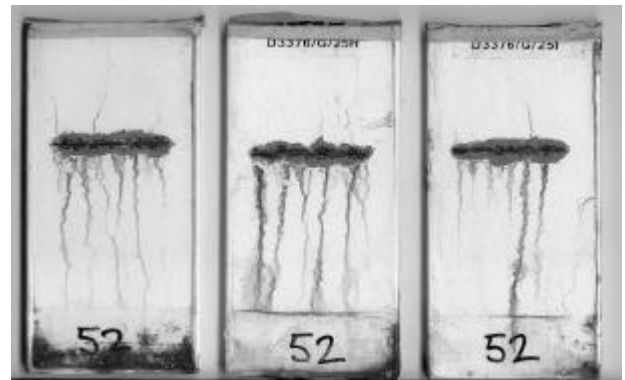
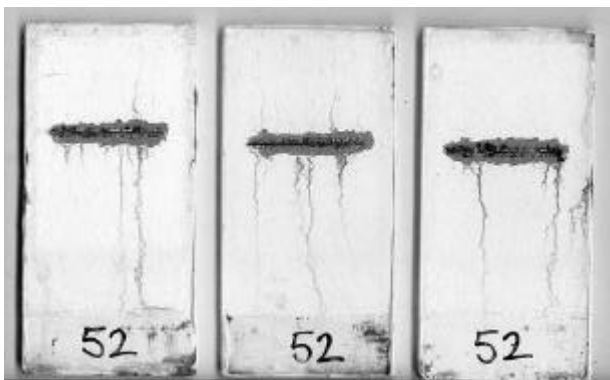


Photo no. 1. Panels after Cyclic salt spray / UVA test



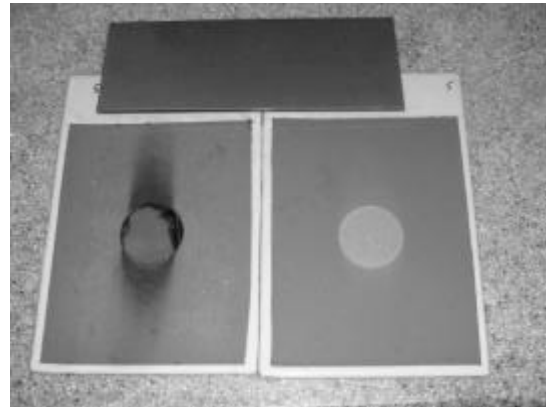
**FIGURE 2 – High solids hydrocarbon modified epoxy**  
**No freeze cycle** **Freeze cycle**



**FIGURE 3 – Standard zinc epoxy/HB epoxy/finish (Sa2½ grit blasted steel)**  
**No freeze cycle** **Freeze cycle**



**FIGURE 4 – Open circuit potential set-up**



**FIGURE 5 – Zinc rich epoxy primed panels – left poor, right good**

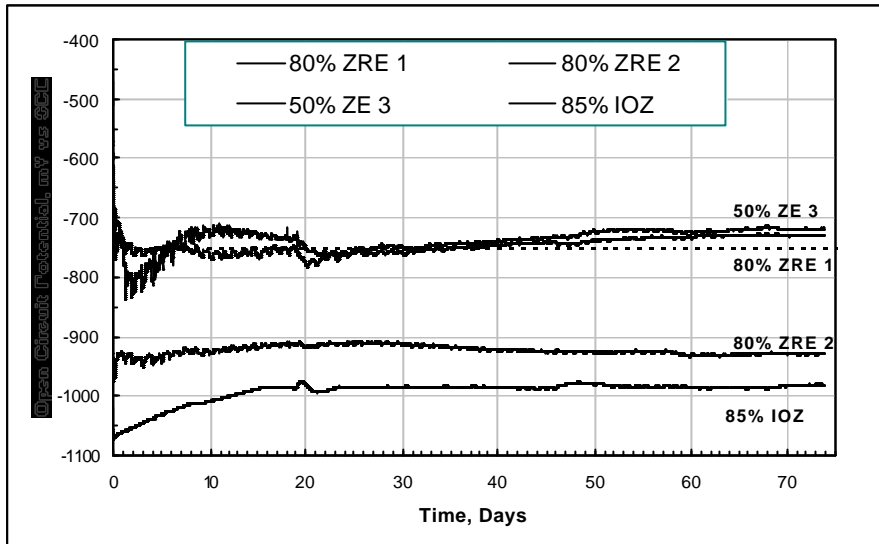


FIGURE 6 – Open circuit potential data for zinc rich epoxies and zinc silicate



FIGURE 7 – Internal stress measurement



FIGURE 8 – Coated shim under test

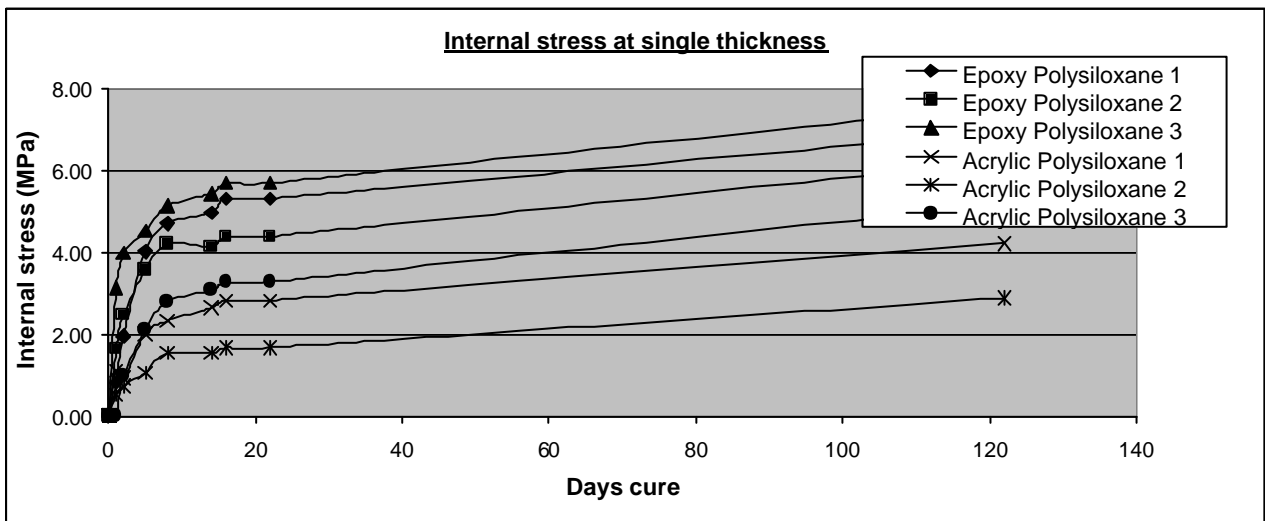


FIGURE 9 – Effect of chemistry of polysiloxane on internal stress at 125 microns (5 mils) dry film thickness