MACLEAN POWER SYSTEMS
A MacLean-Fogg Company

Engineering Test Report

C17P009
Testing of TransArmour Coatings
For Pole Line Hardware

Abstract:
This report details the type testing conducted on hardware with a binary coating system for improved corrosion resistance. Mechanical and accelerated corrosion tests were conducted on the test subjects. The results support that items protected with binary system of hot dip galvanizing and top coated with TransArmour polymer can provide a comparable service life as a stainless steel item.

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1. Introduction

Standard hot dipped galvanized pole line hardware applied in corrosive environments are subject to a short service life. The options available to combat corrosion has been either frequent maintenance (replacement), or switch to a different material, specifically stainless steel. Both options require significant investment: frequent maintenance has a recurring cost (high lifetime cost) and the stainless steel option has a high initial cost.

Improving the corrosion resistance of standard pole line hardware using a binary coating system can provide the similar service-life performance of stainless at a lower initial cost. MacLean Power Systems has partnered with TransArmour (Pelahatchie, MS) to protect pole line hardware using a system of polymer resin over hot dip galvanizing.

It is the purpose of this report to provide a description of the TransArmour coating system and present the results of corrosion and durability testing. The objective of TransArmour coatings for hardware is to provide the performance (service life) of stainless steel, but at a comparatively reduced cost.

<u>Product description</u>

Duplex coatings have been utilized in many applications and range from the simple paint over hot dip galvanizing to highly-engineered epoxy resins over hot dip galvanizing. The design intent with any duplex coating is that both layers work together, in a synergistic manner, to provide a longer service life than either one applied alone.

MacLean Power's TransArmour coated hardware line is rated to 7500 hours of ASTM B117 salt fog resistance and is comprised of a single layer of polymer resin over hot dip galvanizing conforming to ASTM A153. The polymer resin is infused with aluminum particles and provides both a physical barrier and a resilient ultraviolet coating. Figure 1 depicts the protection layers of the protection system. Catalog numbers use a "TA" suffix to denote the protection system (i.e. J8810-TA).

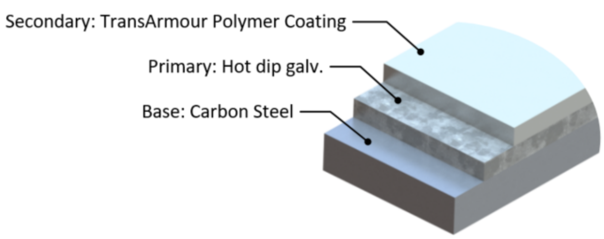

Figure 1: Detail of the TransArmour coating.

The polymer resin is sprayed on top of the hot dipped galvanized hardware. The TransArmour-coated offering for pole line hardware includes machine bolts, pole top pins, cross arm pins, steel cross arms, and eye bolts.

Square nuts, used with machine-thread fasteners, are hot dipped galvanized per ASTM A153 and then coated in Teflon to provide sufficient corrosion resistance and allow disassembly even after prolonged exposure. For easy differentiation, the square nut used with TransArmour hardware is black in color.

2. Test Descriptions

Mechanical Testing

Tensile Testing was conducted per ASTM F606. The test set up is depicted in Figure 2.

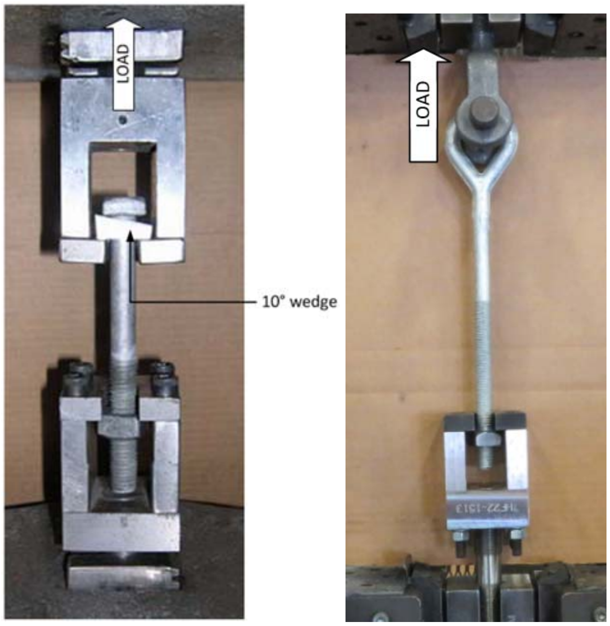

Figure 2: Test set up for tensile testing of bolts (machine bolt left, oval eyebolt right).

Four different corrosion tests were conducted and are described below as:

Corrosion Test #1: Salt Fog Exposure (Items Pre-conditioned with Sand Abrasion)

Salt fog exposure per ASTM B117 (test subjects preconditioned with sand abrasion). The salt fog is a static condition test and uses a 5% NaCl solution at 95°F for the duration of the test. The pH of this test is considered neutral and ranges from 6.5 to 7.2.

Corrosion Test #2: Ultraviolet-Salt Fog Cyclical Exposure (Items Pre-conditioned with Sand Abrasion)

Conducted per ASTM D5894, this cyclical test combines accelerated weathering with corrosion testing, which stresses the coating on a sample more than a standard salt fog test. Cyclical testing better mimics the changing nature of in-service environmental conditions. The salt fog portion of this test is acidic with a pH range of 5.0 to 5.4, which better simulates industrial pollution. One complete Ultraviolet-Salt Fog cycle is two weeks long and is defined as:

Test segment	Temperature	Segment Duration	Cycle Duration	Applicable Standard
Ultra-violet exposure	140° F	4 hrs	Repeat segments for 168 hrs (one week)	ASTM D 4587
Condensation	122° F	4 hrs		
Salt fog (.05% NaCl and .35% $(NH_4)_2SO_4$)	Ambient	1 hr	Repeat segments for 168 hrs (one week)	ASTM G85 (A5)
Drying period	95° F	1 hr		

For both corrosion test #1 and #2 described above, sand abrasion was applied to a defined area of the test subjects prior to testing. The sand abrasion was a controlled and repeatable method of stressing the polymer coating prior to corrosion exposure testing. The sand abrasion was applied per ASTM D968 and is defined as funneling two liters of sand onto the coating surface (Figure 3). The resulting effect of sand onto the coating surface is depicted in Figure 4.

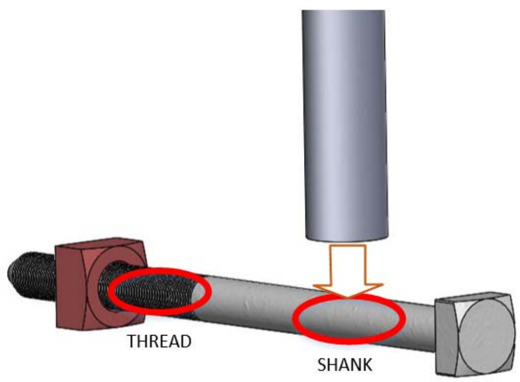

Figure 3: Sand Abrasion Set Up

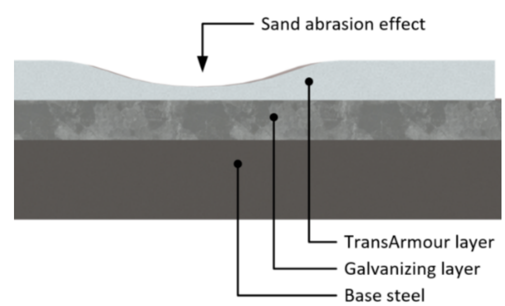

Figure 4: Effect of sand on coating cross section

<u>Corrosion Test #3: Ultraviolet-Salt Fog Cyclical Exposure (no sand abrasion preconditioning)</u>

Ultraviolet-Salt Fog cyclical exposure per ASTM D5894 (no preconditioning). Same cyclic test as above without sand abrasion on the samples. This test had a duration of ten cycles.

<u>Corrosion Test #4: Gravelometer followed by Ultraviolet-Salt Fog Cyclical Exposure</u>

Gravelometer testing per ASTM D3170 was followed by ultraviolet-salt fog cyclical exposure per ASTM D5894. The test bolts were subjected to impacts by road gravel between 3/8” and 5/8” in size and then placed into the cyclic corrosion test for three complete cycles. Using the gravelometer provides a controlled and reproducible manner of compromising the polymer coating and exposing the galvanizing layer beneath it to corrodents. The effect of the gravel onto the surface coating is shown in Figure 5.

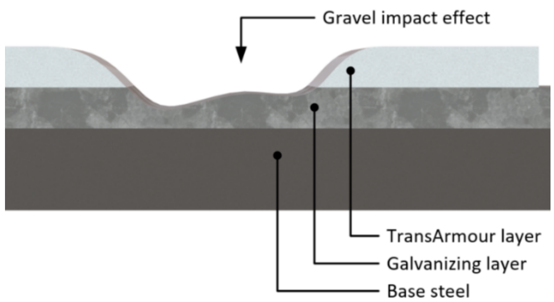

Figure 5: Effect of gravel impacts on coating cross section

For all corrosion tests: Evaluation of the samples were visual-based and referenced ASTM D610.

3. Test Results

Mechanical Test #1: Tensile

Samples of 5/8” machine bolts and eyebolts with TransArmour coating were tensile tested to destruction per ASTM F606 (apparatus was an Instron #300DX-C3A). For comparison, hot dipped galvanized bolts and thermal diffusion galvanized bolts were also tensile tested. The test results are found in Table 1. The minimum requirement for MacLean Power 5/8” machine bolts is 13,550 lbs (per ASTM A307). All items exceeded the minimum tensile requirement.

Table 1: Tensile Test Results (in lbs.)

		Minimum requirement per:		Actual:
Catalog Number	Test Subject Description	ANSI C135.1	ASTM A307	UTS
J8810	5/8" X 10" Machine Bolt (Hot dip galv.)	12,400	13,550	19,186
J8810	5/8" X 10" Machine Bolt (Hot dip galv.)	12,400	13,550	18,880
J8810-T	5/8" X 10" Machine Bolt (TDG)	12,400	13,550	19,858
J8810-T	5/8" X 10" Machine Bolt (TDG)	12,400	13,550	19,772
J8810-TA	5/8" X 10" Machine Bolt (TransArmour TA)	12,400	13,550	19,798
J8810-TA	5/8" X 10" Machine Bolt (TransArmour TA)	12,400	13,550	18,956
J9412-T	5/8" X 12" Oval Eye Bolt (TDG)	12,400	13,550	17,903
J9412-TA	5/8" X 12" Oval Eye Bolt (TransArmour TA)	12,400	13,550	17,581

Corrosion Test #1: Salt Fog Exposure (Items Pre-conditioned with Sand Abrasion)

The test samples listed below in Table 2 were subjected to sand abrasion per ASTM D968 and then salt fog exposed for 1000 hours per ASTM B117. Testing was performed by an A2LA laboratory (Applied Technical Services, Inc. in Marietta, Georgia). Hot Dipped Galvanized samples complied with ASTM A153, and thermal diffusion galvanized (TDG) samples complied with ASTM A1059. The evaluation rating after the 1000 hours (per method detailed in ASTM D610) is noted in the table. Photograph of the bolts before salt fog exposure can be seen in Figure 7 and post-test in Figure 8. Of note is the discoloration at the sand abrasion area appears similar in pre-test and posttest.

Table 2: Salt Fog Test Results

Sample ID#	Test Subject Description	Sand Abrasion Location	Rating (1000 hrs)
TA13	5/8" X 12" Machine Bolt (TDG)	Shank	7
TA14	5/8" X 12" Machine Bolt (TDG)	Thread	7
TA15	5/8" X 12" Machine Bolt (TransArmour TA)	Shank	9
TA16	5/8" X 12" Machine Bolt (TransArmour TA)	Thread	9
TA19	5/8" X 12" Machine Bolt (Hot dip galv.)	Shank	2
TA20	5/8" X 12" Machine Bolt (Hot dip galv.)	Thread	2

Figure 6: Bolts pre-test (1000-hour salt fog)

Figure 7: Post 1000 Hour Salt Fog

The discoloration seen on the TransArmour TA bolts immediately after sand abrasion was mostly unchanged when observed after the 1000-hour salt fog exposure. This supports the TransArmour coating was resilient against the sand abrasion to prevent a concentrated attack of the substrate zinc and steel in the salt fog exposure. Figures 10 through 15 in Appendix A contains side-by-side photos of the bolts at 0 and 1000 hours.

Corrosion Test #2: Ultraviolet-Salt Fog Cyclical Exposure (Items Pre-conditioned with Sand Abrasion)

The samples specified below in Table 3 were pre-conditioned with sand abrasion per ASTM D968 and then subjected to a UV-Salt Fog cyclical test per ASTM D5894 for a total of three complete cycles. Testing was performed by an A2LA laboratory (Applied Technical Services, Incorporated in Marietta, Georgia).

Table 3: UV-Salt Fog Cyclic test results after three cycles

Sample ID#	Sample Description	Rating at end of cycle Three	Sand Abrasion Loc.	Appearance of Abrasion area
TA25	5/8" X 12" Machine Bolt (TDG)	7	Shank	No change pre- to post test
TA26	5/8" X 12" Machine Bolt (TDG)	7	Thread	No change pre- to post test
TA27	5/8" X 12" Machine Bolt (TransArmour TA)	8	Shank	No change pre- to post test
TA28	5/8" X 12" Machine Bolt (TransArmour TA)	8	Thread	No change pre- to post test
TA31	5/8" X 12" Machine Bolt (Hot dip galv.)	6	Shank	Zinc oxide found post test
TA32	5/8" X 12" Machine Bolt (Hot dip galv.)	6	Thread	Zinc oxide found post test

Figure 9 shows the samples pre-test and Figure 10 depicts the samples after three complete cycles (six weeks) of testing. The review of samples post-test was based on the amount of corrosion products observed on the coating. This visual review yielded the following ranking:

- TransArmour samples TA 27 and TA 28: had the best coating appearance. Shank area exhibited minor discoloration. No products of corrosion found.
- Thermal diffusion galvanizing samples TA 25 and TA 26: moderate discoloration and zinc oxide products of corrosion were found on approximately 35% of the sample's surface.
- Hot dip galvanized samples TA 31 and TA 32: ranked last based on appearance with discoloration and products of corrosion found on approximately 75% of the sample's surface.

The preconditioned areas did not exhibit a significant change in appearance on the TransArmour and TDG items. The hot dipped galvanized items exhibited white zinc oxide in the preconditioned areas.

Figure 8: Bolts before cyclic UV/Salt Fog (preconditioned with sand abrasion)

Figure 9: Bolts after three cycles of UV and Salt Fog (preconditioned with sand abrasion)

Corrosion Test #3: Ultraviolet-Salt Fog Cyclical Exposure (no sand abrasion preconditioning)

Sample bolts were subjected to the ultraviolet-salt fog cyclic testing per ASTM D5894, with no preconditioning, for a total of ten cycles. The results are detailed below in Table 4. Photographs of the samples were taken at the end of cycles five and ten and are contained in Appendix B of this report as Figures 16 and 17.

Table 4: Results of Cyclic Testing (no sand abrasion)

Sample ID#	Sample Description	Cycle Five	Cycle Ten
14	Eyebolt TransArmour TA	7	6
15	Eyebolt Hot Dipped Galv	3	2
18	Eyebolt 304 Stainless Steel	3	3

Similar to the results of corrosion test #2, the TransArmour TA bolts exhibited the most resistance to weathering and corrosion attack compared to the other coating types and 304 stainless steel.

Corrosion Test #4: Gravelometer followed by Ultraviolet-Salt Fog Cyclical Exposure
Bolts were subjected gravelometer testing per ASTM D3170 and followed by cyclic corrosion exposure per ASTM D5894 (three cycles). The gravel impacts resulted in chips sized less than 3mm in diameter. The cyclic corrosion exposure produced zinc oxides (white in color), which signified the zinc layer was still present and able to protect the steel substrate. No red rust was found, nor was any undercutting of the TransArmour polymer layer observed. Photos of the test subjects can be found in Appendix C as Figures 18, 19, and 20.

4. Discussion

The results of the static salt fog test and cyclic UV-salt fog test demonstrate the TransArmour coatings outperform TDG and hot dipped galvanizing in terms of both resistance to corrosive attack and breakdown of the protective coating.

TransArmour TA items use a single polymer layer over hot dipped galvanizing and has the following key characteristics:

- a high bond strength to the underlying zinc
- infused with aluma particles which adds strength and abrasion resistance
- includes UV stabilizers to resist breakdown

The result is a high strength barrier, which prevents outside corrodents from reaching the underlying metal layers.

Discoloration of the TransArmour coating seen after the cyclic salt fog can be attributed to a reaction with the acidified salt spray rather than UV exposure. This is substantiated by comparing the TransArmour samples of the static (neutral salt fog) and the cyclic (acidified) salt fog. Also, the discoloration was found around the part and not just the side facing the UV lamps.

The threaded areas of TDG and hot dipped galvanized (HDG) samples exhibited more discoloration and corrosion attack than the TransArmour items. This can be partially attributed to the surface roughness of the TDG and HDG items. The threads of these items easily capture moisture during testing, and the surface roughness increases the wettability of this area. More wetness time results in more time for corrosion attack to occur. The TransArmour coated items have a smoother surface, which allows for moisture to dry, or shed off, more easily compared to the TDG and HDG items.

Preconditioning with the sand abrasion had little effect on the TransArmour and TDG samples. This can be attributed to the high barrier strength of the TransArmour polymer layer. Similarly, the TDG coating is an intermetallic mix of zinc and iron with a higher hardness value than the outer layers of zinc found on HDG items.

The gravelometer test was chosen for its ability to simulate chipping of the TransArmour coating. The corrosion testing done afterwards showed the exposed zinc layer protected the steel substrate.

Additionally, the TransArmour coating surrounding the chip remained intact and adhered to the zinc beneath.

It should be noted the cyclic UV-salt fog testing is a very different test than the static salt fog test. The static salt fog provides a rapid attack of metallic coatings due to the constant wetness exposure, which does not occur in real-world applications. The cyclic test incorporates segments that mimic in-service conditions (i.e. thermal cycling, UV exposure, wet/dry cycles) and can test both painted coatings and metallic coatings. A conservative estimate is seven cycles of the cyclic ASTM D 5894 correlates to 5,000 hours of the static ASTM B 117 test. Thus, fourteen cycles can be considered 10,000 hours in the static ASTM B 117 test.

5. Conclusion

TransArmour coated hardware items are suitable for highly aggressive environments such as coastal areas mixed with industrial pollution. The TransArmour TA items use a multilayer system to prevent corrosion attack and withstand ultraviolet breakdown. The TransArmour TA items can withstand an equivalent 10,000 hour salt fog test, which places the coating on par with stainless steel items.

The advantage of the TransArmour coated items is their cost effectiveness compared to stainless steels. TransArmour items use carbon steel as the base metal, which is easily transformed (forged) into fasteners and other hardware and is less costly than stainless steel. Additionally, TransArmour items comply to ASTM A 153 and ANSI C135.80 due to the primary layer of hot dipped galvanizing beneath the polymer layer.

Appendix A: ASTM B117 Sample Figures

Figure 10: Sample TA13 salt fog comparison

Figure 11: Sample TA14 salt fog comparison

Figure 12: Sample TA15 salt fog comparison

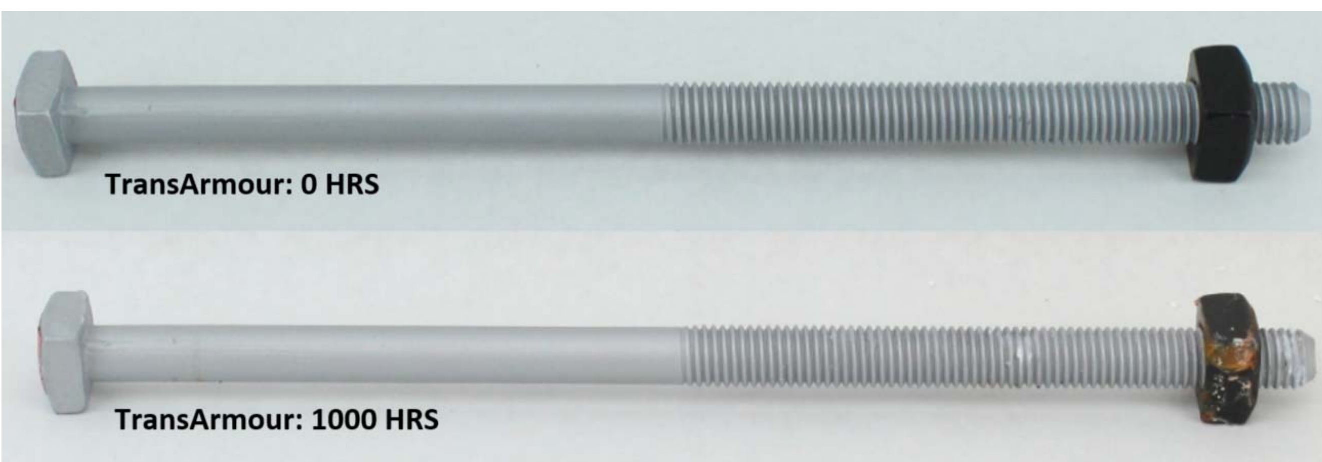

Figure 13: Sample TA16 salt fog comparison

Figure 14: Sample TA19 salt fog comparison

Figure 15: Sample TA20 salt fog comparison

Appendix B – Cyclic UV-Salt Fog Testing (Corrosion Test #3)

Figure 16: Test items at the end of cycle 5 (Left to right: TransArmour, hot dip galvanized, Stainless steel)

Figure 17: Test items at end of cycle 10 (top to bottom: TransArmour, Hot Dip Galv, Stainless steel)

Appendix C – Gravelometer Test (Corrosion Test #4)

Figure 18: TransArmour-coated bolts after gravel impact (before cyclic corrosion testing)


Figure 19: TransArmour-coated bolt, gravel impacted, after cyclic corrosion exposure

Figure 20: TransArmour-coated bolt, gravel impacted/after cyclic corrosion exposure; zoom in view, no undercutting observed

END OF REPORT