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LIGHT-WEIGHT DRAPABLE ANTI-CORROSION COVERS

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ABSTRACT

At the onset of the Second World War, it was noticed that equipment being shipped overseas to the frontlines arrived corroded. The Department of Defense rapidly escalated the use of corrosion inhibitors in packaging materials to reduce the severity of the corrosion of those assets. This paper provides an overview of vapor corrosion inhibitors, describes how they are incorporated into anti-corrosion covers, and summarizes field test results showing typical protection provided to Department of Defense assets. The paper describes the environmental conditions that warrant the use of anti-corrosion covers and presents independent ground vehicle focused return-on-investment analysis.

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1. INTRODUCTION

The use of anti-corrosion covers with Vapor Corrosion Inhibitors (VCIs) continues to expand throughout the Department of Defense. Field performance is measured to demonstrate the efficiency and effectiveness of these covers used on a range of military equipment exposed to different environmental conditions.

The paper discusses the environmental conditions that warrant the use of anti-corrosion covers and provides examples of their efficacy in corrosion minimization.

The paper then discusses a Business Case Analysis (BCA) prepared by Jensen Hughes for the Army Corrosions Control and Prevention Executive [1]. The BCA ties the ISO Corrosivity Categories and the cost of the cover to determine a Return on Investment (ROI) and provides guidance on cover use. The paper then presents data on cover VCI longevity and discusses how this may affect the calculated cover ROI and guidance on their use.

1.1. Background

Transhield started supplying anti-corrosion covers to the military in 2000. Shortly thereafter development of a more robust green material, XT, commenced to address the rigors of USMC use. A secondary color, tan, was requested resulting from engagement with Camp Pendleton.

As USMC use grew, the U.S. Army started acquiring XT covers. Examples of XT anti-corrosion covers protecting M1A1 Abram tanks, Strykers and JLTVs are shown in Figures 1, 2 and 3 respectively.

Figure 1: M1A1 tanks protected by a tan XT cover.

Figure 2: A Stryker protected by a green XT cover.

Figure 3: JLTVs protected by a tan XT cover.

Around the turn of the century, the U.S. Navy sought a better solution to protect assets from corrosion than traditional canvas and vinyl tarps and initiated a Small Business Innovation Research project to develop anti-corrosion covers. The first generation of anti-corrosion covers, with VCIs, were approved by NAVSEA21 in 2003 and the fleet was outfitted with covers for a large variety of equipment ranging from weapons systems to deck equipment.

In 2013 NAVSEA21 approved Transhield's ArmorDillo®, a second-generation anti-corrosion cover with VCI technology, that enables a more form-fitted cover to be made.

2. COMBATTING THE CORROSION CYCLE

Corrosion may require repair and it often impacts maintenance availabilities. Perhaps even more problematic is weapon systems and electronics degradation and their impact on readiness and safety. Successful corrosion management leads to a reduction in total ownership cost by managing maintenance which has a flow on effect of enabling greater operational flexibility.

Coatings, including polysiloxane and chemical agent-resistant coatings (CARC), are designed to protect the metal substrate from the corrosive environment.

Coating systems fail from exposure to ultraviolet (UV) radiation, chemical and biological agents, freeze-thaw cycles and abrasion. The corrosion rate [2] is exacerbated by the coating failure rate, starting a cycle that degrades over time as shown in Figure 4.

Prolonged UV exposure results in the deterioration of organic coatings, a process known as photo-oxidation deterioration. CARC "flat gloss" systems are more prone to photo-oxidation deterioration since they absorb more UV and infrared radiation than gloss finishes.

Chemical and biological induced damage increased dramatically over the years in line with an increase in the concentration of carbon dioxide, sulfur dioxide, greenhouse gases, and other pollutants. These pollutants produce water-soluble salts, a precondition for acid rain which over time damages and breaks down all coatings and finishes.

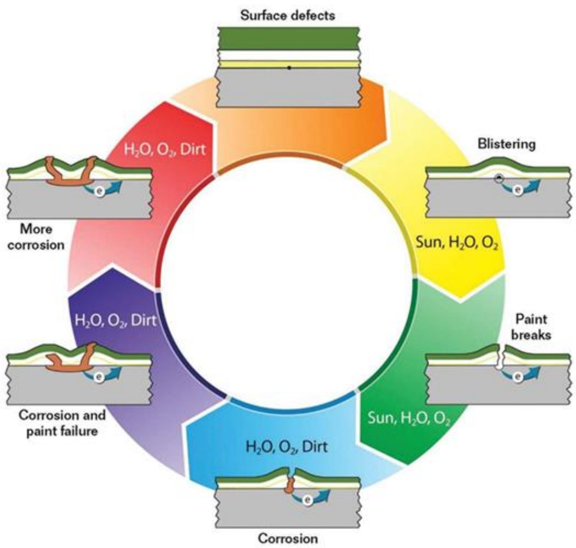

Figure 4: Paint failure and corrosion cycle.

Precipitation and humidity all accelerate the corrosion rate. Daily condensation and dew will pond in all coating surface micro-cracks. As the water expands during a freeze-thaw cycle, it also expands the surface micro-crack allowing more water to pond. As the cycling continues, the micro-cracks grow both wider and deeper, until the crack penetrates the full coating thickness exposing the metal substrate to water and the corrosion cycle commences.

Abrasion causes coating damage when dust, dirt, mud, gravel, rocks, wind, snow, ice, and other solid materials impact the coating. Abrasion severity depends on impact energy, impact angle and repetition.

The driving force for metallic corrosion is the change in Gibbs energy (ΔG), as the system seeks a lower energy state. Three of the most common corrosion mechanisms of painted metal are blistering, cathodic delamination, and anodic delamination [3].

Blistering is triggered when surface impurities are exposed to water. Cathodic delamination requires a micro-crack in the paint film and the presence of either oxygen or water to establish anodic and cathodic sites. Aluminum substrates are susceptible to anodic delamination; the aluminum oxide layer is consumed in an anodic reaction, which weakens the bond between the paint and the substrate.

In summary, multiple mechanisms may initiate coatings failure and only one is required to start the corrosion cycle.

3. ANTI-CORROSION COVERS

Transhield's anti-corrosion covers contain a soft, inert, hydrophobic fiber to protect painted surfaces and glass from rubbing that occurs between the cover and the surface resulting from wind and precipitation.

The first line of defense provides protection from UV radiation, chemical and biological agents, precipitation and debris. Designed to be effective even when temperatures range from -30 to 140°F, these covers have excellent long term UV protection, providing up to 99% protection.

A waterproof membrane that is also water vapor permeable protects metals against corrosion better than a less permeable membrane or a total barrier [4] and provides the second line of defense. Transhield anti-corrosion covers allow moisture beneath a cover to migrate out, a material property known as the water vapor transmission rate.

Harnessing VCIs, embedded within the anti-corrosion cover itself are emitted from the cover are attracted to the metallic substrate and form a protective molecular barrier and delivers the third line of defense. Results from extensive corrosion inhibitor research reveal that they perform best when in a vapor form. Airborne VCI molecules also provide a self-healing capacity as they are attracted to the bare metal if the VCI barrier is broken. An elegant solution has been found to manage the VCI concentration when bounded by permeable barriers: compound the VCIs with the adhesive used to create the permeable encapsulation [5], as shown in Figure 5.

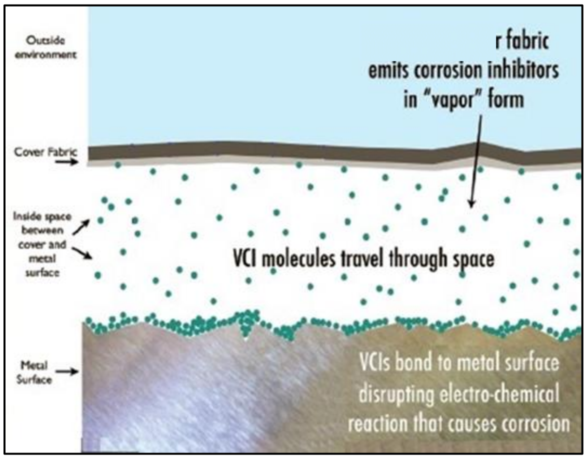

Figure 5: VCI migrating and bonding to the metal.

4. PERFORMANCE MEASUREMENT

Two methods to quantify corrosion are: visual inspection and mass loss.

At the onset of corrosion ASTM D610 provides a means of visual inspection to quantify spot, general and pinpoint rust [6].

As the degree of corrosion increases, standard test methods include either mechanical, chemical or electrolytic means of removing the corrosion byproduct from the substrate and to quantify the mass loss measured form a pristine rust-free datum.

ASTM G1 is a mass loss standard [7] also provides a means of calculating the corrosion rate based on the mass loss, coupon specifications and time of exposure.

As the corrosion process continues, the corrosion byproduct is more susceptible to impact, abrasion, wind and gravity resulting in the byproducts being removed from the surface exposing the uncorroded substrate to the corrosion process.

The method employed in this paper is an enhancement of the visual inspection process of ASTM D610 and employs an algorithm to analyze a digital picture and quantify those pixels which indicate corrosion or protection [8]. Protection percentage is quantified after exposure by equation (1), where UP and CP refer to uncorroded and corroded pixels respectively.

$$Protection\% = \frac{\sum UP}{\sum CP\ and\ UP} \times 100 \quad (1)$$

Meaningful quantification of the extent of the corrosion depends upon whether the metal is experiencing the onset of corrosion or whether substantial corrosion has already occurred and that influences the selection of the method to quantify it. The onset of corrosion by visual means and if there is substantial corrosion by mass loss as per ASTM D610.

5. TYPICAL FIELD ASSESSMENT

The effectiveness of anti-corrosion covers with VCI technology is highlighted by the following example of ground forces equipment being transported across the Pacific Ocean [9]. A test was conducted in 2015 at the request of USARPAC and the 25th Infantry Division. Transhield XT and ArmorDillo anti-corrosion covers were placed on an M997 HMMWV Ambulance and MEP-1040 Generator respectively prior to a voyage from Malaysia to Hawaii on board the U.S. Army Logistic Support Vessel-2, CW3 Harold A. Clinger; Figures 5, 6 and 7 respectively.

Bare metal coupons were placed inside and outside the covers to assess the level of protection provided to the asset. The majority of them were paired coupons one inside and another outside the cover, just separated by the cover itself.

At the conclusion of the 35-day voyage, U.S. Army personnel witnessed the removal of the XT and ArmorDillo® anti-corrosion covers and immediately took photographs of the coupons.

Table 1 shows the protection percentage provided to the coupons, and by deduction the MEP-1040 Generator, by the ArmorDillo anti-corrosion cover. All paired coupon results for the MEP-1040 Generator after the 35-day voyage are shown in Figures 8-9.

Figure 5: U.S. Army MEP-1040, 10kW 50/60Hz Generator protected by an ArmorDillo cover

Figure 6: U.S. Army M997 Ambulance HMMWV protected by an XT cover

Figure 7: U.S. Army vessel CW3 Harold C. Clinger Logistics Support Vessel (LSV-2)

The ArmorDillo anti-corrosion cover provided an average 87% protection for all coupons. It would be logical to conclude that they provide similar protection to unpainted metals of the MEP-1040 Generator.

Table 1. MEP-1040 Generator protected by a Transhield ArmorDillo cover

Steel Coupon Designation	Inside Protect %	Outside Protect %
MEP-1040 15 TR	76.07	
MEP-1040 16 TL	75.15	
MEP-1040 17 RS	82.24	
MEP-1040 18 LS	93.21	
MEP-1040 19 IN F	97.32	
MEP-1040 20 OUT F		8.76
MEP-1040 21 IN R	98.42	
MEP-1040 22 OUT R		0.00

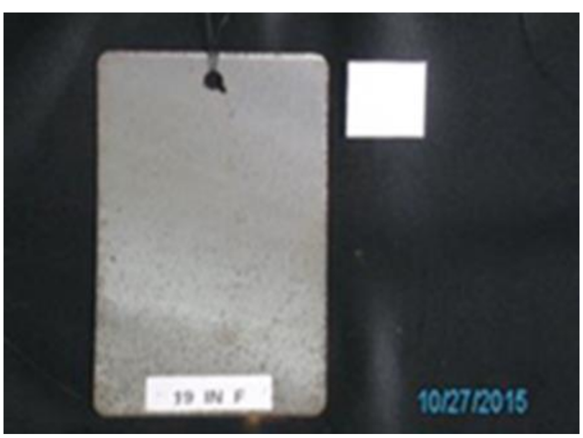

Figure 8.a: Pair A - 19 IN F MEP-1040 Protected

Figure 8.b: Pair A - 20 OUT F Unprotected

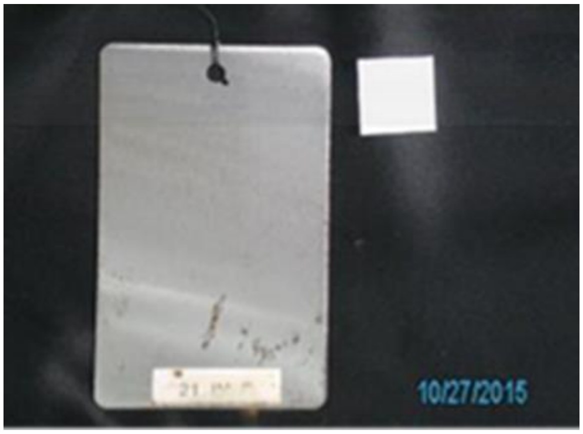

Figure 9.a: Pair B - 21 IN R MEP-1040 Protected

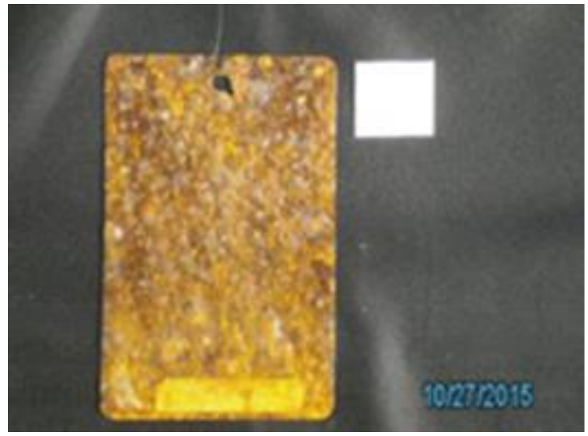

Figure 9.b: Pair B – 22 OUT R Unprotected

In an earlier voyage from Hawaii to Australia in 2015, CARC painted panels were also tested. These panels were scored with an X-Cut to expose bare metal. Paired panels were employed, one protected by an ArmorDillo anti-corrosion cover, the other exposed to the elements.

The bare metal exposed by the X-Cut experienced similar protection to that cited for the bare metal panels. Those results were presented at the 2017 Department of Defense Allied Nations Technical Corrosion Conference [10].

Table 2 shows the protection percentage provided to the coupons, and by deduction the M997 HMMWV, by the Transhield XT anti-corrosion cover while on the Malaysia to Hawaii voyage. All paired coupon results for the M997 HMMWV Ambulance after the 35-day voyage are shown in Figures 10-12.

Coupon 06 IN F did not perform as expected. Examining the percent protection afforded by the Transhield XT anti-corrosion cover, the average was 81.6% when all coupons were included in the calculation. This rises to 94.9% if Coupon 06 IN F is excluded.

Note coupon 08 IN RT fell onto the deck during the voyage and corroded and coupon 09 OUT RT fell off and was lost prior to arrival in Hawaii.

Table 2. M997 HMMWV Ambulance protected by a Transhield XT cover

Steel Coupon Designation	**Inside Protect %**	**Outside Protect %**
M997 HV 01 FH		9.46
M997 HV 02 RS	99.22	
M997 HV 03 RD	98.12	
M997 HV 04 LS	98.63	
M997 HV 05 INPS	99.35	
M997 HV 06 IN F	1.74	
M997 HV 07 OUT F		2.50
M997 HV 08 IN RT	Voided	
M997 HV 09 OUT RT		Lost
M997 HV 10 IN RR	99.95	
M997 HV 11 OUT RR		0.21
M997 HV 12 IN LS	74.65	
M997 HV 13 OUT LS		0.00

It should be noted that an open well deck on an oceangoing ship is an extremely corrosive environment and it is difficult to ascertain what caused Coupon 06 IN F to corrode without 24/7 video surveillance. To properly protect assets, covers should be made of VCI enhanced anti-corrosion cover material, covers should be form-fitting and secured properly to the equipment being protected, and they must be installed correctly.

Two additional examples that highlight the effectiveness of anti-corrosion covers with VCI technology have been previously published [10].

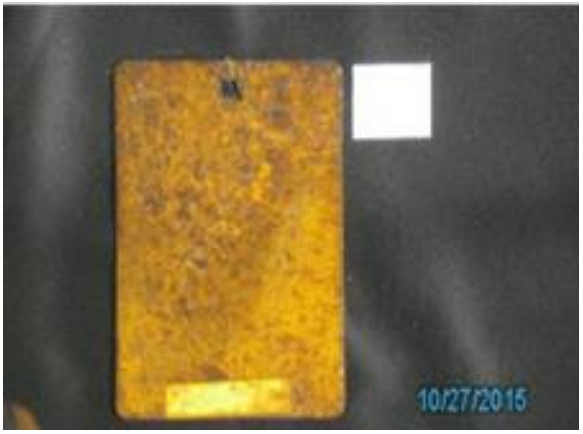

Figure 10.a: Pair A - 06 IN F HV Protected

Figure 10.b: Pair A - 07 OUT F Unprotected

Figure 11a: Pair C - 10 IN RR HV Protected

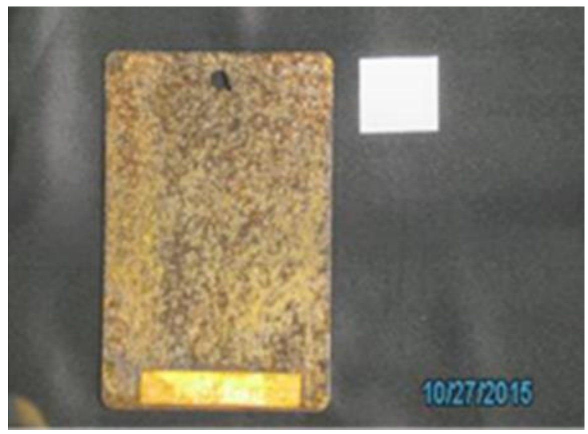

Figure 11.b: Pair C - 11 OUT RR Unprotected

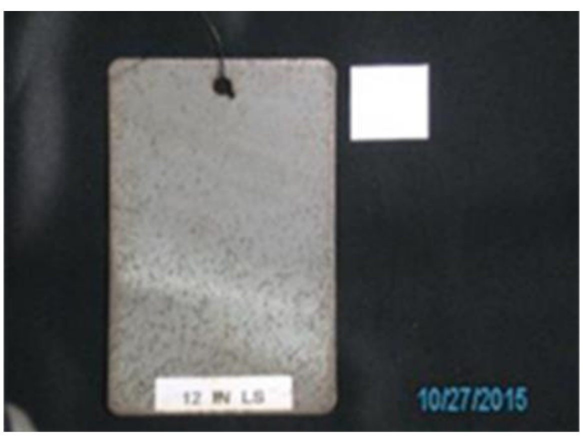

Figure 12.a: Pair D - 12 IN LS HV Protected

Figure 12.b: Pair D - 13 OUT LS Unprotected

The examples presented in this paper for XT and ArmorDillo anti-corrosion covers are associated with highly corrosive areas. The ISO Corrosivity Categories for North American and the northern Pacific Ocean are shown in Figure 13. The ISO Corrosivity Categories for the USARPAC and the 25th Infantry Division assessment on board the U.S. Army Logistic Support Vessel-2, CW3 Harold A. Clinger are at an ISO Corrosivity Category of C3 or higher.

While USMC ground vehicles may operate in highly corrosive environments, not all U.S. Army and USMC ground vehicles operate or are stored in those environments. Significant portions of the mid-west have an ISO Corrosivity Category of C2.

In those mid-west states, especially where wind power is viable, wind-driven dirt and dust may penetrate and damage the asset [11].

Anti-corrosion covers reduce damage resulting from airborne particulates impacting an asset and also protect against degradation resulting from solar exposure. For example, rubber/elastomeric gaskets and tires all degrade under ultra-violet (UV) exposure [12]. This becomes more important when elastomeric gaskets are a key component of barriers against chemical and biological agents.

6. INDEPENDENT RETURN ON INVESTMENT ANALYSIS

The U.S. Army experiences reduced readiness rates and increased corrective maintenance actions; as much as four times higher in areas of high temperature, high humidity and high salinity. To objectively quantify the problem, the Army Corrosion Control and Prevention Executive directed Jensen Hughes to prepare a Business Case Analysis (BCA) [1].

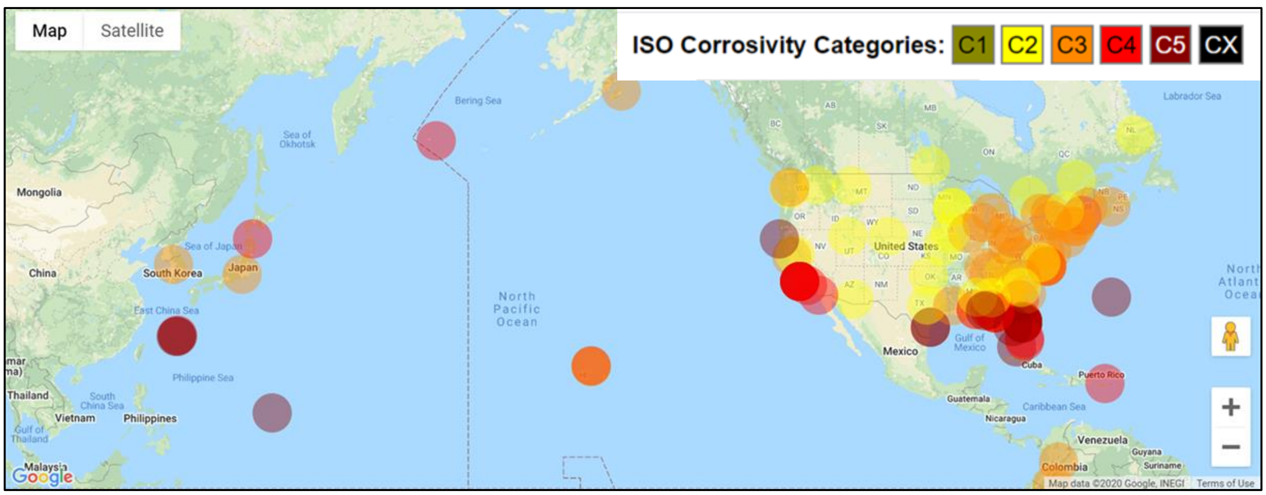

Figure 13: ISO Corrosivity Categories in North America and the Northern Pacific Ocean [13]

Assuming a 20-year lifespan for ground systems, the ROI calculated for covers is 19:1 based on a two-year cover life. The ROI increases if the cover lasts longer than two years or the cover is used to protect assets in more corrosive environments; ISO Corrosivity Category C3 or higher.

Jensen Hughes report recommended that covers should be used where the ROI is 10:1 and/or the ISO Corrosivity Category is C3 or higher as shown in Figure 14.

Their report used a Stryker as the basis of their BAC and the cover they purchased of the assessment cost around $3,200.00 as shown in Figure 15. Superimposed on this figure are indicative costs for ArmorDillo anti-corrosion covers for naval assets.

The U.S. Navy has historically operated in environments which have an ISO Corrosivity Category of C3 or greater. It is reasonable to conclude that the ROI for anti-corrosion covers will likely be higher than those calculated by the BCA for the U.S. Army.

Two ground vehicle XT anti-corrosion covers, that have seen in-service use for over three and seven years respectively, have been tested using Gas Chromatography-Mass Spectrometry and sufficient VCIs were found to indicate that these covers were still effective [14]. The BCA ROI calculation adjustment, based on the VCI longevity data, is closer to 40:1 as shown in Table 3.

Table 3: ROI as a function of VCI presence in a cover

VCI Presence (Years)	ROI
2	19:1
3	29:1
4	39:1

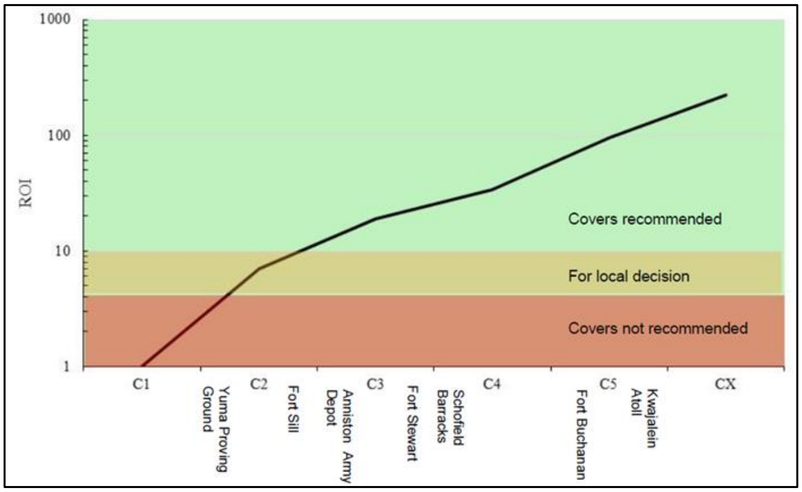

Figure 14: Recommendation to Implement Simple Covers Based on ROI and ISO Corrosivity Category [1]

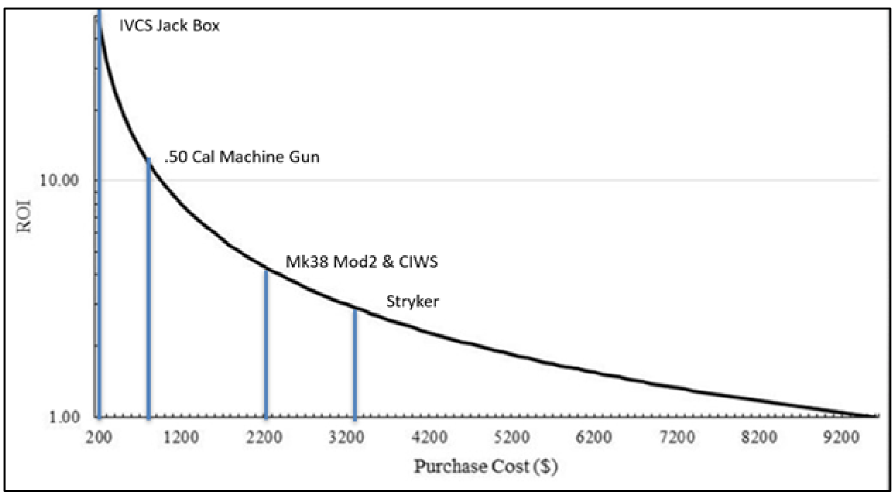

Figure 15: Break-Even Point of Equipment Covers Depending Upon Purchase Cost [1]

While the US Army ROI assessment focused entirely on ground vehicles and concluded that an ISO Corrosivity Category C3 or higher was one criterion for selecting covers, the US Army has almost 4400 active aircraft in its inventory compared to 5200 for the USAF [15].

The USAF's 309th Aerospace Maintenance and Regeneration Group operates the boneyard in Tucson Arizona where covers are used.

Transhield XT and ArmorDillo covers also support the storage preparation preventing foreign object damage (FOD) and reducing corrosion.

ArmorDillo anti-corrosion covers designed to protect an F-16's engine inlet from FOD and an Apache main rotor and M-TADS from corrosion and FOD are shown in Figures 16 and 17 respectively.

Figure 16: An ArmorDillo cover protecting an F-16's engine inlet from FOD.

Figure 17: An ArmorDillo cover protecting an Apache rotor and M-TADS from corrosion and FOD.

Covers are relevant in environments where the ISO Corrosivity Category is less than 3. Transhield's XT and ArmorDillo covers provide protection against corrosion but in some instances FOD protection is the primary reason for their purchase.

7. WHAT IS NEXT

Naval Surface Warfare Center Port Hueneme Division and Transhield, under two Cooperative Research and Development Agreements, have developed Counterforce EMD (Counterforce) a drapable material, to mitigate an adversary's ability to utilize the EMS to interfere with tactical operations. Initially it was designed to prevent adversarial interrogation of topside radar communication and combat systems when ships are in port, it can also be used to manage signature emissions, mitigate interference and damage to critical assets (microwave DEW and EMP).

Counterforce prevents friendly signals emanating from a vehicle and if a five-sided cover is integrated into the vehicle's body can provide protection against damage caused by Counterforce EMD covers also employ VCI technology to combat corrosion.

8. CONCLUSION

Transhield XT and ArmorDillo covers provide significant protection against corrosion for DoD assets in highly corrosive environments and foreign object damage in less corrosive environments.

Independent analysis recommends the use of covers when the ROI is 10:1 and/or the ISO Corrosivity Category is C3 or higher.

Protecting ground vehicles from damage resulting from airborne particulates impacting an asset and also protect against degradation resulting from solar exposure is applicable to all ISO Corrosivity Categories. Elastomeric gasket effectiveness degrades with UV exposure and its integrity is key to an effective barrier against chemical and biological agents.

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