USE OF VOLATILE INHIBITORS (VCIs)
FOR AIRCRAFT PROTECTION

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ABSTRACT

A variety of tests were performed to evaluate the feasibility of VCIs application for maintenance and protection of Navy aircraft from corrosion damage.

In the test program such procedures, as a Salt Fog Cabinet ASTM B-117 and Humidity Chamber ASTM D-1748 were performed to evaluate the protection properties of inhibitor A to be applied primarily on airframes, armaments and mechanical parts.

Inhibitor A, is a complex mixture of amine salts of aromatic sulfonic acids in the carrier, and volatile carboxylic acid salts as a vapor phase inhibitor. Inhibitor A possessed both contact and vapor phase inhibition properties.

Inhibitor B, a polyethylene film extruded with VCI compound was specified in the test program. Inhibitor **B** is a mixture of amine carboxylates. This inhibitor was evaluated as a barrier material possessing VCI and desiccant properties. Specially designed climatic tests have been performed to assess protection properties of this inhibitor.

Inhibitor C, containing triazoles, amines, carboxylic acids, salts and esters, was tested using the Battelle Flowing Mixed Gas test + ASTM-1748. The Battelle Flowing Mixed Gas Test and ASTM-1748 have been applied on the following metals: steel, aluminum, copper, gold, silver, solder, brass in order to simulate the effect of indoor environments on electronic components and materials. The Battelle test is considered to be a realistic, accelerated environmental test since it takes into account the synergistic effect of low concentrations of relevant pollutants, temperature and humidity. The test condition simulated was a Class III environment.

KEY TERMS: Vapor corrosion inhibitor, Navy aircraft maintenance, protection of avionics equipment.

INTRODUCTION

This paper will address VCI materials developed by Cortec Corporation that have provided advances in corrosion control of naval aircraft.

Prevention of aircraft deterioration is the central theme of any maintenance effort including the Naval Aviation Maintenance Program (NAMP). The possibility of significant corrosion damage is greatest when aircraft are inactive, in transport, in storage, or when poorly protected and maintained. As a general rule, tactical aircraft spends only about 40% of their time in active flight missions. Therefore their reliability and sustained performance are a direct result of protective and preventive maintenance measures on the flight deck or hanger.

The materials used in the construction of aircraft include aluminum alloys, magnesium alloys, high-strength steels, titanium alloys, composite materials and other non-ferrous metals used in the avionics equipment. Numerous corrosive agents can have an adverse effect on the aircraft structural materials. Water is always present, usually not from exposure to rain, but as a result of condensation; spillage's and leaks of hydraulic fluids, lubricants and fuel; highly corrosive chloride and sulfate ions in the air - to name just a few. This list of potential environmental dangers to naval aircraft is not all inclusive. It is influenced and continually altered by advances in technology, geographical location and strategic/tactical threat.

It is not surprising that over the years, examples of all the common types of corrosion have been found on aircraft. These include crevice, pitting and exfoliation corrosion on aluminum alloy components; galvanic corrosion at dissimilar metal contacts and dynamic corrosion processes such as stress corrosion cracking; all types of electronic corrosion; corrosion fatigue and fretting corrosion.

In order to maintain military aircraft as a ready to mission unit, different maintenance schemes can be employed. The protection schemes currently used on military aircraft have been evolved over a period of 30 to 40 years and are designed to protect the aircraft throughout its life. There are six traditional classes of corrosion preventive systems commonly used in the military and commercial aviation. They are: protective coatings (polyurethane's, epoxies); inorganic finishes (chrome, cadmium plating, anodizing); corrosion-inhibitive compounds (water displacing oils); sealants (silicones, polysulfides); corrosion-resistant alloys; desiccants.

A largely overlooked application for aircraft protection is the technology of volatile corrosion inhibitors (VCI). This paper is an attempt to fill this gap and provide the interested audience with prospects of possible use of these compounds for aircraft maintenance and protection.

EXPERIMENTAL PROCEDURE

Materials and Apparatus

The procedures for the general corrosion tests performed on inhibitor **A** followed the ASTM practices B-117 and D-1748. Low carbon steel Q-panels were utilized according to SAE 1010 as the surface preparation before inhibitor **A** application. The original finish was used and cleaning with methanol was performed to avoid surface contamination.

A special apparatus (see Fig. 1) was designed for the testing of Inhibitor **B** (extruded with vapor corrosion inhibitor in polyethylene film). All metal samples were polished, degreased and cleaned with methanol. Steel, copper, brass and aluminum panels of 7x5x0.2 cm each were mounted on the test holder and packed into inhibited polyethylene film bag, and a bag of nontreated polyethylene as a control. The bags were sealed airtight. Inside each bag was approximately 20 grams of water in the form of a saturated sponge. The samples were arranged inside the test assembly so as not to be touched by the bag. The bags were placed in a temperature cycling climate chamber so that water within the bags could condense on the samples and the bag walls. The temperature settings were 45^{o} C (113^{o} F) and 15^{o} C (59^{o} F) respectively for each cycle. Every four hours the temperature was switched from one setting to another. The duration of the test was 42 cycles or 168 hours. Water condensed on the samples was monitored periodically by visual inspection. The surface area of the bag interior was 0.1 m^2.

As the test procedures for the inhibitor C - a product specially formulated for protection of the aircraft electronic equipment - two methodologies were used:

* **ASTM D-1748 Humidity Cabinet Method**
* **Battelle Flowing Mixed Gas Test**

The ASTM D-1748 accelerated corrosion test was performed at elevated temperature and humidity. The extent of protection provided by the inhibitor **C** was determined. The following metals were used in the test: silver, solder, copper, brass and steel. Test panels of 3.75 x 7.5 x 0.16 cm were cleaned with methanol before use. For each metal one panel was untreated, another one was sprayed with the inhibitor **C**. Panels were allowed to air dry and then placed in an ASTM D-1748 humidity cabinet with relative humidity of 100% and temperature of 50^{o} C.

The Battelle Flowing Mixed Gas test was used to determine the effectiveness of the inhibitor **C** in a polluted environment. The test was developed in Battelle Laboratories to simulate the effect of indoor operating environments on electronic components and materials. The following metals were used in the test: copper, silver, gold and steel. The metal samples were cleaned with methanol before the application of inhibitor **C.** Environmental conditions inside and chamber were:

a) Temperature	**:**	**30^{o} C**	μ	**2^{o}**
b) Relative humidity	**:**	**75%**	μ	**2%**
c) Cl_2 concentration	**:**	**20 ppb**	μ	**5 ppb**

d) NO_2	**:**	**200 ppb**	**μ**	**50 ppb**
e) H_2S	**:**	**100 ppb**	**μ**	**20 ppb**
f) Exposure time	**:**	**7 days**		

After stabilization, the test samples and control coupons were placed in the chamber no closer than 5 cm from each other or the chamber. After placement of the samples in the chamber, it was allowed to re-stabilize and adjust as required to maintain the specified concentrations and conditions.

RESULTS AND DISCUSSION

The anti-corrosion performance of the inhibitors

<u>Inhibitor A performance in ASTM D-1748 and B-117 tests</u>

The performance of inhibitor **A** is shown in Fig.'s 2, 3 and 4. As it can be seen, the film of inhibitor **A** with a thickness of 12.5 microns provided protection for 1500 hours and 37.5 micron film provided protection for more than 2500 hours respectively for steel. A similar pattern of performance was observed for aluminum coated with inhibitor **A.**

In ASTM B-117 salt spray test the duration of protection is 200 hours and 500 hours, respectively, for 12.5 and 37.5 microns film. The control sample failed in 2 hours in humidity cabinet and in 30 minutes in salt fog cabinet. Such a performance of the inhibitor **A** can be attributed to both contact and vapor inhibition abilities of the compound. The inhibitor **A** is a complex mixture of amine salts of aromatic sulfonic acids in the carrier, as a contact inhibitor component, and volatile carboxilic acids salts, as a vapor phase inhibitor. The thin polar layer composed of surfactants, like sulfonated salts, is tightly bound to the metal surface by mechanism of chemisorption. Between this thin polar layer and the corrosive environments is the thicker barrier layer which is usually made up of hydrocarbons. The reason combinations of different surface active components are used in the formulation of inhibitor **A** is that a metal surface has many active sites where corrosion can begin. These active sites have a great range of energy levels. A surface active component of the inhibitor will be strongly chemisorbed or adsorbed at active sites having energy levels complimentary to the energy levels of the polar group. Thus, it would form much tighter and more uniform layer over the metal surface.

The barrier layer has three important characteristics:

* <u>low permeability</u> by moisture and other corrosives
* <u>compatibility</u> with the oleophillic ends of the polar layer molecules so that the barrier is held firmly in place
* <u>good solubility</u> in the carrier so it is possible to apply the polar and barrier layers to the metal surface

Inhibitor **A** also provides protection in vapor phase for metal surfaces not covered or not sufficiently covered with the product due to presence of the volatile part in the formulation. Inhibitor **A** releases a vapor of corrosion inhibitor which migrates to recessed areas or areas not sufficiently protected with the contact part of the inhibitor. It is believed that these ionic vapors form a thin, monomolecular layer on the metal surface providing protection by the mechanism of passivation for steel and aluminum. VCI film barrier reheals and self-replenishes through further evaporation and condensation of the inhibitor on the metal surface. Inhibitor **A** has a much greater affinity for a metal surface than for water. The sulfonate part of the inhibitor displaces water from the metal and becomes chemisorbed on the surface. Therefore, inhibitor A has multifuncitonal properties: <u>corrosion-inhibitive</u> compound, <u>water displacing</u> compound and <u>vapor corrosion inhibitor.</u>

These properties are critically important for protection of airframes, mechanical parts of aircraft and armaments during storage and operation in highly corrosive environments. Inhibitor **A** is also more economical to apply, because it combines in itself protective parameters of three currently used preventive systems.

<u>Inhibitor B performance</u>

The test results on the inhibitor **B** are presented in Table 1. As it is shown, the control metal samples in non-treated polyethylene bag were severely corroded. Metal samples protected with VCI extruded polyethylene bag are practically free from any corrosion attack. The mechanism of protection for inhibitor **B** material is basically the same as it was described above. The carrier for the vapor phase inhibitor is polyethylene film by itself. Inhibitor released by polyethylene matrix migrates through the volume of air to the metal surface and forms a thin protective layer at the surface. It is believed that steel and aluminum are protected by the mechanism of passivation. The works of Miksic and Sparrow (6) revealed that mechanism of protection for copper and copper based alloys, (i.e. brass) is different and based on chemisorption of the inhibitor on the surface and formation of insoluble organometallic complex on the surface. It is important to mention here that inhibitor **B** is a dual function product, as it also provides action of dehumidification along with inhibition. Therefore, inhibitor **B** can be used in the form of insert bags, flexible covers and barrier material in order to protect different parts of aircraft during shipment, storage, etc.

<u>Inhibitor C performance</u>

The number of days to failure of the metal panel when exposed in the humidity cabinet is summarized in Table 2 and Figure 5, for each metal used in the test. It can be seen that solder, copper and brass have an extremely long period of protection when treated with inhibitor **C.** Steel and silver have somewhat less, but still sufficient duration of protection.

The results of the Battelle flowing mixed gas test are shown in Table 3. The most dramatic and explicit visual results were observed for copper, silver and gold, three metals that are very common in different types of electronic devices. Copper control sample was dark black after 1 day of testing, control gold coupon was extensively damaged by pitting with a substantial amount of corrosion creep from the pores and silver was covered with thick black deposit of corrosion products. In comparison copper and gold treated with inhibitor C did not show any signs of corrosion and silver sample was only slightly discolored near edges. The proposed mechanism of protection is chemisorption of the inhibitor on these particular metals. In the case of aluminum, steel and solder, it is believed that absorption is purely physical with subsequent passivation of metal surface.

CONCLUSIONS

The purpose of this paper was to investigate the possibility of application of different types of vapor corrosion inhibitors for aircraft protection during maintenance, storage, transporation and active mission periods.

Inhibitors that can be used for protection of aircraft bodies, armaments, avionics were tested on selected metals mostly common in the aircraft construction, and under specific conditions of accelerated testings.

On the basis of test results it can be concluded that multifunctional VCI systems are technologically feasible and are an economical method for providing corrosion protection to military.

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Table 1.

Material	Inhibitor B	Non-treated polyethylene
STEEL	Free from corrosion	Uniform corrosion, pitting
COPPER	Slight darkening	Dense black film
BRASS	Free from corrosion	Black specks
ALUMINUM	Free from corrosion	Gray-black cast

Table 2.

	DAYS TO FAILURE				
TYPE	Ag	Solder	Cu	Brass	Steel
Control	3	10	4	1	3
Inhibitor	18	66	>80	>80	63

Table 3.

Metal	Control	Inhibitor C
COPPER	Dark deposit	Free from corrosion
BRASS	Dark deposit	Discoloration of edges
SILVER	Black film	Discoloration of edges
GOLD	Pitting	Free from corrosion
STEEL	100% Brown rust	3% Brown rust

FIGURES

Figure 1. Test Apparatus

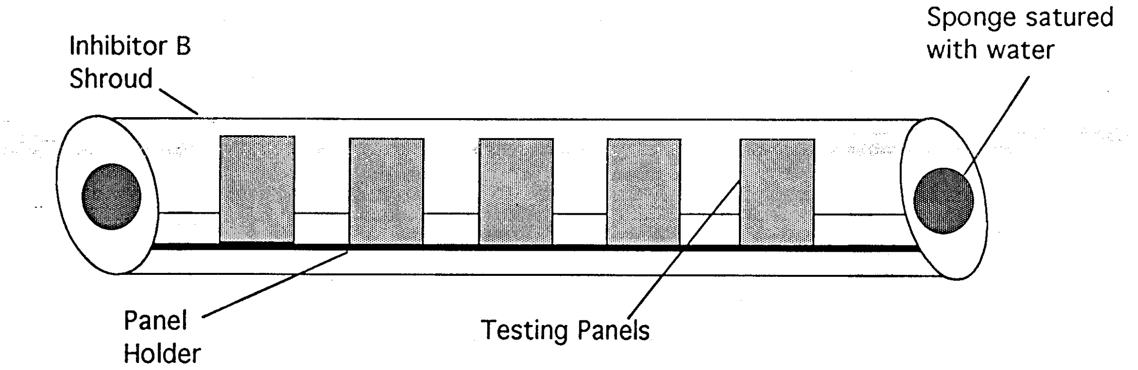


Figure 2. ASTM D-1748

Steel

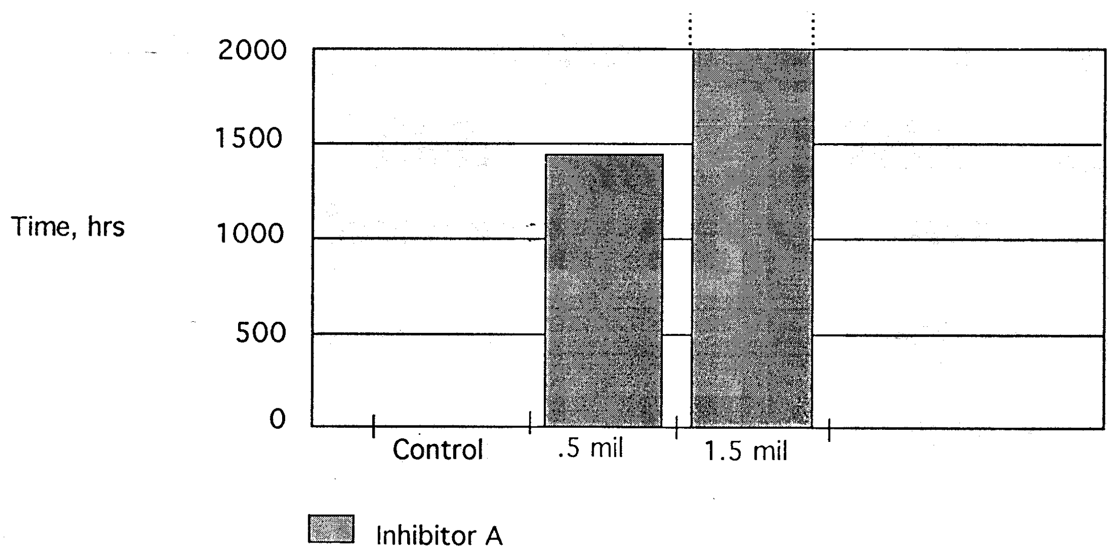


Figure 3. ASTM B-117 Test

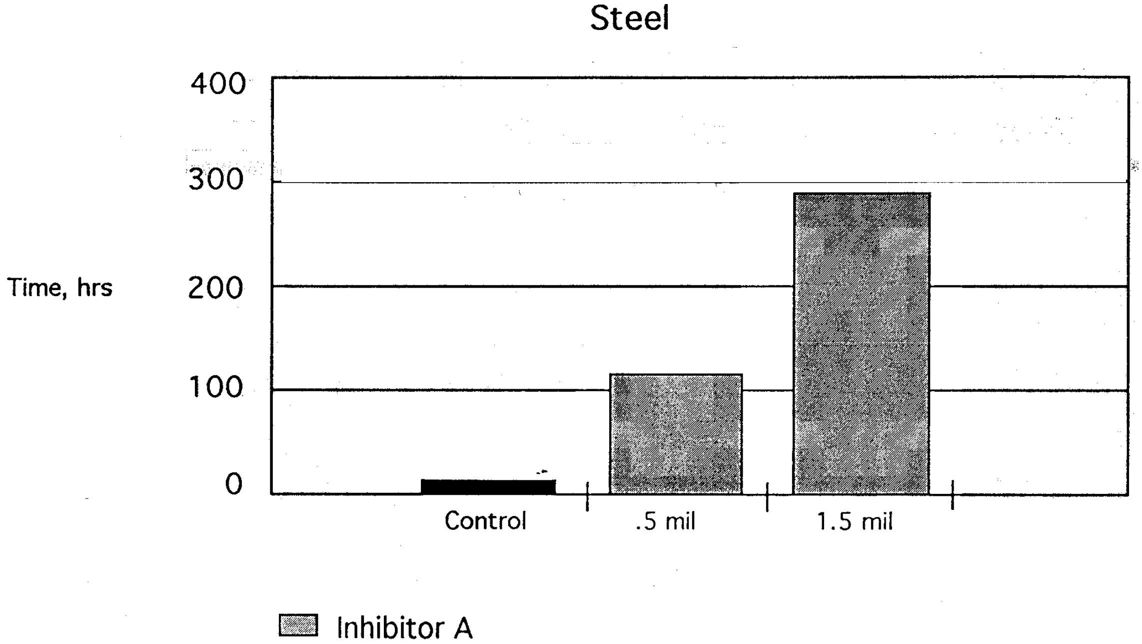


Figure 4. ASTM D-1748

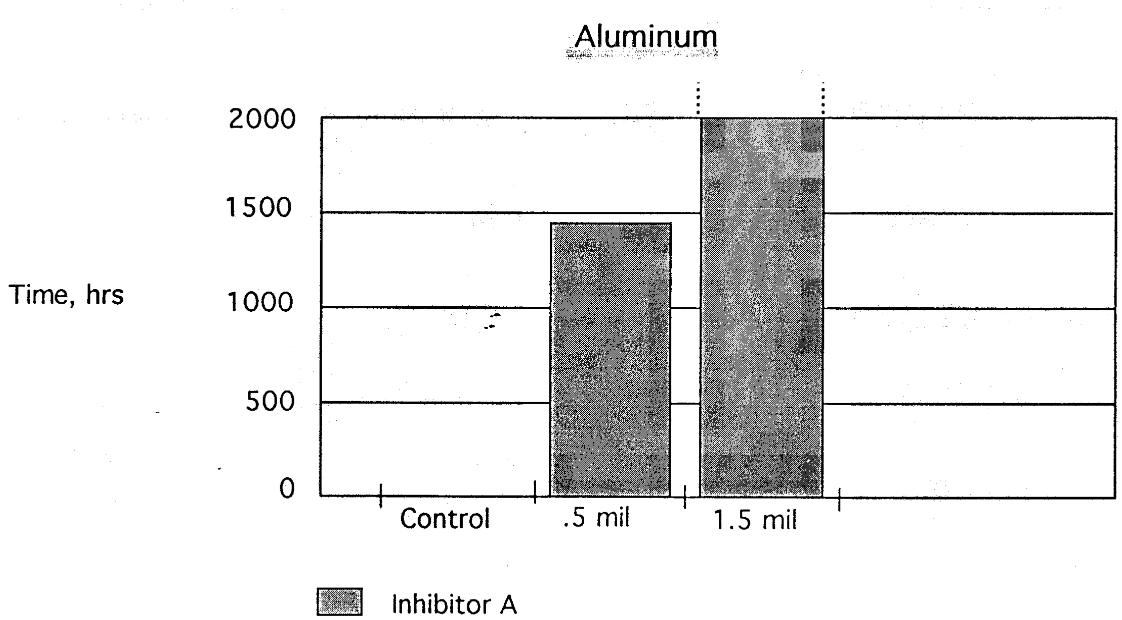
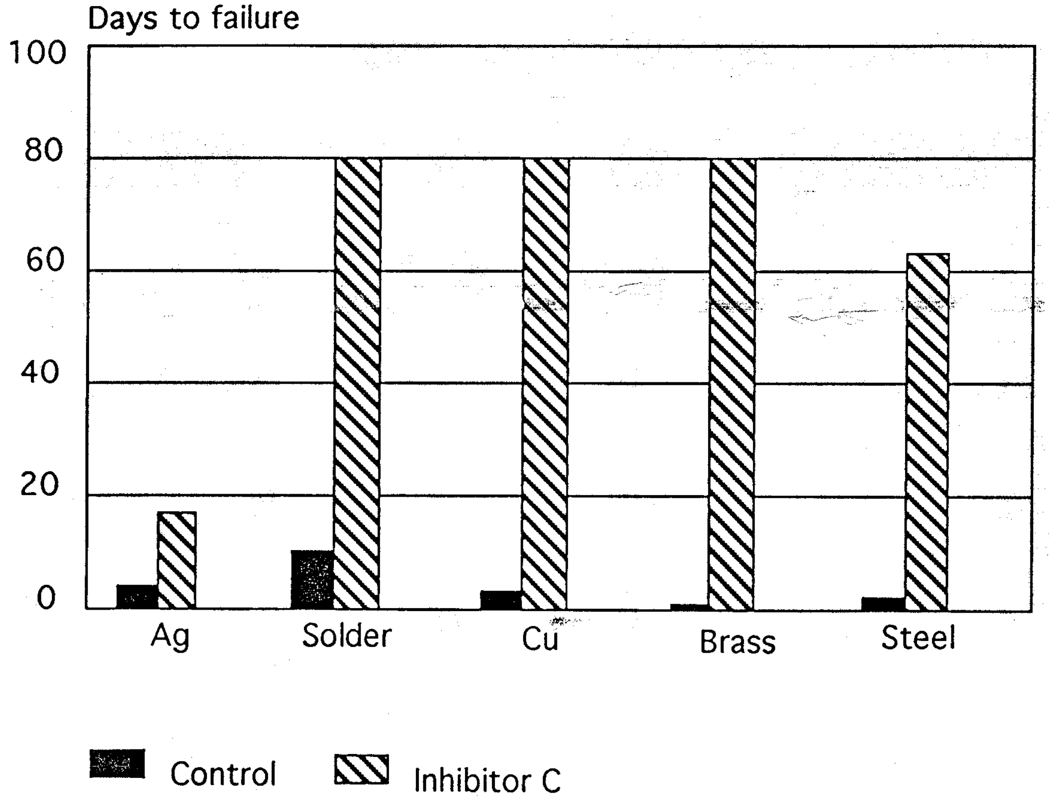


Figure 5. ASTM D-1748 Humidity Cabinet



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