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Incorporating VCIs into Multi-Layered Packaging Materials for Long Term Corrosion Protection

Robert Boyle
Cortec Corporation
4119 White Bear Parkway
White Bear Lake, MN 55110

Cliff Cracauer
Cortec Corporation
4119 White Bear Parkway
White Bear Lake, MN 55110

Brian Wuertz
Cortec Corporation
4119 White Bear Parkway
White Bear Lake, MN 55110

ABSTRACT

For decades many industries have relied on barrier film and vacuum-sealing to protect high value parts and equipment against corrosive attack. Although effective at preventing corrosion over long periods of time, there are several practical disadvantages including time required for packaging, high cost of materials used, and reliance on maintaining packaging integrity for the entire protective period. In response to these limitations, the use of single-layer VCI packaging films gained wide acceptance as a lower cost, easier to use, more durable protective packaging method, achieving preservation periods of up to five years. Most recently, multi-layer VCI packaging materials and technologies have allowed the long-term benefits of barrier films to be combined with the practical advantages of VCI packaging, offering protection periods of up to 15 years.

INTRODUCTION

Several industries ranging from military and telecommunications to aerospace and automotive are plagued by corrosion. The high value equipment and parts used in these industries must be stored for periods up to 15 years due to the high cost of manufacturing parts after production lines are converted to new parts and equipment. Automotive build-ahead programs, for example, typically require 5, 7, 10 and 15 year protective periods based on the quantity and cost of the parts to be preserved.

Prior methods used for corrosion prevention included barrier films in combination with desiccant or moisture-reducing methods, such as nitrogen purges or vacuum sealing. While generally effective, this method is relatively expensive and can be easily compromised due to the rigorous handling and environmental conditions during the preservation period.

Single-layer VCI films were utilized effectively for periods of up to five years and provided a more durable, user-friendly clean packaging method for these industries. By actively saturating enclosed air spaces, VCI impregnated films offered several practical and technological benefits, as described below.

VCI films function by saturating enclosed airspace with the protective molecules. The ability of VCI films to protect is primarily dependent on the vapor pressure and sublimation rates of the chemicals utilized. Humidity within the package causes the molecules to ionize. This polarity thus causes a physical adsorption onto all metal surfaces. This action self-replenishes, allowing a more active protection mechanism, even when packaging is compromised during inspection or rough handling.

VCI films are typically transparent, allowing visual inspection of preserved equipment without the need to compromise the packaging. In contrast, users of barrier films are oftentimes forced to compromise the packaging in order to inspect protected parts. Users are oftentimes presented with a dilemma. If inspected, the user must repackage or recondition the environment, further adding to cost. If not inspected, the user will not know if corrosion exists, until it is more severe.

VCI packaging has a built-in defense mechanism, unlike barrier film products. As temperature and humidity increase, causing a more corrosive environment, the VCI packaging films emit more protective molecules, as the molecules emit at a faster rate. Barrier films, in contrast, are entirely dependent on maintaining a barrier to oxygen, moisture and other corrosive gases.

These same beneficial chemical and practical properties of single-layer VCI protective films create inherent limitations for protective periods longer than five years. Nearly all VCI films are extruded with the VCI molecules contained within the polymer, as opposed to being coated on a single side. Additionally, the typical polymers used in the extrusion of VCI products have some permeability to moisture vapor, oxygen and other contaminants. For these reasons, VCI molecules escape the package while moisture and oxygen enter the package, depleting the protective ability over periods greater than five years.

While single-layer VCI films have proven to be an extremely effective form of protection for periods up to five years, there is a large market demand for longer term protection methods that combine the benefits of barrier films with the benefits of VCI technology. The result of several years of research was the development, evaluation and subsequent introduction of multi-layered VCI protective films.

In the first embodiment, single layer VCI film is laminated to metallic, static-shielding foil, using a tie-layer to promote and ensure long-term adhesion between the dissimilar materials. The resultant multi-layer film product allows users to follow the exact same application procedure as is used for single-layer VCI films. Significantly longer protection periods are achieved as corrosive elements and gases are kept out of the package and VCI protective molecules are kept in. The same self-replenishing action of the VCI film occurs within the package.

The second embodiment builds on the initial successes of the first embodiment by incorporating a third functional layer (and a second tie-layer, for five total layers) of polyester-based barrier film. The five-layer structure allows further reduction of moisture and oxygen transmission rates, increased strength and durability, static-shielding and static dissipative properties and longer overall periods of protection. Unlike barrier films, both embodiments of multi-layer VCI films described above can achieve protection for greater than five years without requiring vacuum sealing, nitrogen purge or desiccant.

Further testing was conducted to ensure compatibility between VCI emitter devices and the multi-layer VCI packaging films. VCI emitter devices are used to increase the quantity of VCI within a package and volatilize and saturate an enclosed space at a faster rate than VCI film alone. As previously described, most VCI film products are produced using blown film extrusion where the VCI chemistry is encased within the film product. Therefore, there is an inherent blooming effect that occurs on the film's surface wherein the VCI chemistry reaches the surface and subsequently volatizes until saturation is reached within the package. VCI emitter devices volatize without the blooming effect exhibited in VCI films. Saturation within the packaged is therefore attained at a rate faster than the film alone can attain.

VCI emitter devices also serve a practical purpose during long storage periods. VCI emitters can be replenished at a lower cost than repackaging, when preserved items are removed from packaging for various reasons.

EXPERIMENTAL PROCEDURE

In conducting evaluations on the relative protective ability of single-layer VCI and multi-layer VCI products, standardized accelerated corrosion testing was used, as reflected in the ASTM D 1748-83 "humidity cabinet" method . Additionally, military specifications for barrier film serve as a guide for comparison of physical properties between barrier films and multi-layered VCI products. Physical property testing was conducted to ensure multi-layer VCI products have the same or greater physical properties. Finally, standardized and industry accepted VCI performance tests including Federal Standard 101c "German VIA Test" and the "Razor Blade" test, modeled on Military Standard

3010a, Method 3005, were performed in order to ensure that multi-layer VCI products meet or exceed the standards used in evaluating single-layer VCI products.

Standardized tests and modified versions were conducted over a period of several years in order to evaluate the relative protective ability offered by multi-layer VCI films. The modifications required were due to the precise needs of the marketplace. In addition to the carbon steel panels that are used in the standardized testing, actual equipment and parts were used in the same testing. These modifications were required to more accurately reflect variation in part size, type of metal(s) used and application method. The combination of standardized and modified test methods allowed a comprehensive comparison between barrier films, single-layer VCI films and multi-layer VCI films.

RESULTS AND DISCUSSION

In the first round of modified ASTM D 1748-83 testing, single-layer VCI bags were compared to multi-layer VCI bags. Parts packaged with both of these methods were inspected every four weeks. The level of corrosion was noted at each interval, expressed in terms of the percentage of surface area, where corrosion was present. By combining the results of the accelerated testing with known real-world results achieved with single-layer VCI films, the length of protection offered in real-world applications can be approximated for multi-layer films.

The results of the testing on the multi-layer VCI bags showed corrosion on 0-1% of the parts' surface area after 12 weeks in the humidity cabinet. After only four weeks, the parts protected with single-layer VCI bags showed corrosion on 1-5% of the surface area. These results show an approximate three-fold increase in the protection offered by the multi-layer VCI bags, as detailed in Table 1.

Using the same modified ASTM D 1748-83 method, further testing was used to compare the relative protection offered by multi-layer VCI bags to the protection offered by low-density polyethylene film alone. After three weeks in the humidity cabinet, minor corrosion was observed on the multi-layer VCI protected parts and the test was concluded. As was expected, the parts protected in the multi-layered VCI bag showed only three small areas of corrosion. Parts protected with low density polyethylene film alone were severely corroded on all surfaces, as detailed in Table 2.

In order to verify that multi-layer VCI films meet the same quality specifications used in evaluating single-layer VCI films, the German VIA test and Razor Blade test were conducted. The German VIA test was conducted to determine if effective amounts of corrosion inhibitor molecules were emitted into an enclosed space. Grades 2 or 3 are typically acceptable. To test for contact corrosion inhibition offered by multi-layer VCI products, the "Razor Blade" test was conducted, where the results are expressed in pass/fail format.

The results showed that multi-layer VCI products can meet the same performance specifications as single-layer VCI products that use the same base VCI chemistry in their formulation. The test results comparing single-layer and multi-layer VCI products to barrier films are shown in Table 3.

A modified ASTM D 1748-83 method was again used in evaluating the relative protection offered by non-VCI LDPE film, non-VCI barrier film and multi-layer VCI film. An unprotected, unpackaged part was also included in the testing as a control.

The test shows that corrosion initiates within one day for the control, four days for non-VCI LDPE film and within eight days using MIL-PRF-131J, Class 1 barrier film. In contrast, multi-layer VCI film showed no signs of corrosion even after 12 days in the humidity cabinet. Results from this test are shown in Table 4.

The results of the physical properties of multi-layer VCI film were conducted according to the standard practices for each property. As detailed in Table 5, the results show that multi-layer VCI films have physical properties that meet or exceed military specifications that cover many barrier films currently on the market.

CONCLUSION

Based on the combination of results detailed above, it can be concluded that multi-layer VCI films are capable of providing corrosion protection for periods longer than single-layer VCI films. Single layer VCI films can offer protection of up to five years, while multi-layer VCI films can offer protection for up to 15 years. Multi-layer VCI films also offer corrosion protection for significantly longer periods of time than barrier films and under a wider range of storage conditions. In comparison to barrier films, multi-layer VCI films tend to be easier to apply, with a lower application cost and longer resultant protective period.

REFERENCES

1. ASTM D 1748-83 "Standard Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet"
2. Federal Standard 101c, Method 4031, Procedure B, "Corrosion Inhibiting Ability of VCI Vapors"
3. Military Standard 3010a, Method 3005, "Contact Corrosivity"
4. ASTM D 646 "Standard Test Method for Grammage of Paper and Paperboard (Weight per Unit Area)"
5. ASTM D 2103 "Specification for Polyethylene Film and Sheeting"
6. ASTM D 882 "Test Methods for Tensile Properties of Thin Plastic Sheeting"
7. ASTM D 1922 "Test Method for Propagation Resistance of Plastic Film and Thin Sheeting by Pendulum Method"
8. ASTM F 88 "Test Method for Seal Strength of Flexible Barrier Materials"
9. ASTM 1249 "Test Method for Water Vapor Transmission Rate through Plastic Film and Sheeting using a Modulated Infrared Sensor"
10. ASTM D 3985 "Test Method for Oxygen Gas Transmission Rate through Plastic Film and Sheeting using Coulometric Sensor"

Table 1
MODIFIED ASTM D 1748-83 CORROSION TEST RESULTS

Layers in Sample	Modified Test Method Used	Surface Area Corroded (%)	Duration in Cabinet (Weeks)	Estimated Protection Offered (Years)
1	ASTM D 1748	1-5%	4	5
3	ASTM D 1748	0-1%	12	15

Table 2
MODIFIED ASTM D 1748-83 CORROSION TEST RESULTS

Protection Used	Test Method	Duration	Corrosion Result
Multi-Layer VCI	ASTM D 1748	3 weeks	3 spots, 1 side
LDPE non-VCI	ASTM D 1748	3 weeks	Severe, All Sides

Table 3
VCI AND BARRIER FILM CORROSION TEST RESULTS

Test	Single Layer	Multi-Layer	Barrier Film
Razor Blade Test	Pass	Pass	Fail
German VIA Test	Grade 3	Grade 3	Grade 1

Table 4
MODIFIED ASTM D 1748-83 CORROSION TEST RESULTS

Protection Used	Test Method	Time Until Corrosion (Days)
None: Control	ASTM D 1748	1
LDPE non-VCI Film	ASTM D 1748	4
Barrier Film	ASTM D 1748	8
Multi-Layer VCI Film	ASTM D 1748	> 12

Table 5
PHYSICAL PROPERTIES OF MULTI-LAYER VCI FILM

Property (Units)	Test Method	Value
Basis Weight (kg/ream)	ASTM D 646	62.95
Caliper (mm)	ASTM D 2103	221
Tensile Strength (kPa)	ASTM D 882	MD 26,871 / TD 21,359
Puncture Resistance (g)	Fed Std 101	0.043
Elmendorf Tear (g)	ASTM D 1922	MD 750 / TD 1100
Heatseal Strength (kg/cm)	ASTM F 88	2.6-3.5
Water Vapor Transmission Rate (g/100in2)	ASTM 1249	<0.001
Oxygen Transmission Rate (cc/100in2)	ASTM D3985	<0.001