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COMPARISONS OF FIBER TUBE AMMUNITION CONTAINER VARIANTS FOR MOISTURE PERMEABILITY AND ABSORPTION

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13. ABSTRACT (Maximum 200 words)

The U.S. Army currently packs certain ammunition in its standard wax-impregnated fiber containers. Unfortunately, these containers are not entirely satisfactory. The wax inside the fiber container melts and exudes out under extremely hot conditions and deposits on the cartridge which can lead to malfunctions. Other, unwaxed fiber containers (e.g., those used to pack 120 mm tank ammunition) sometimes absorb and may be permeable to water or water vapor. This causes several problems: the tube may swell, making it difficult to remove the round; metal parts in the shell may corrode; and explosive stabilizers may deteriorate. Therefore, an urgent task was initiated to develop a new container that ameliorates these problems by minimizing moisture penetration. A number of modifications to the existing container have been identified, including five different types of container exterior coatings, an additional construction material in the container wall laminate, and two mechanical closure types. This document describes a testing program conducted to provide quantitative comparisons of the moisture permeability of containers with these alternatives to the permeability of nontreated (without exterior coating) containers.

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INTRODUCTION

The U.S. Army currently packs certain ammunition (for example, the 81 mm mortar round) in its standard wax-impregnated fiber containers. Unfortunately, these containers are not entirely satisfactory. The wax inside the fiber container melts and exudes out under extremely hot conditions and deposits on the cartridge, which may lead to malfunctions. Other, unwaxed fiber containers (e.g., those used to pack 120 mm tank ammunition) sometimes absorb and may be permeable to water or water vapor. This causes several problems: the tube may swell, making it difficult to remove the round; metal parts in the shell may corrode; and explosive stabilizers may deteriorate. Therefore, theARDEC Packaging Division, sponsored by the Project Manager of Ammunition Logistics, initiated an urgent task to develop a new container that ameliorates these problems by minimizing moisture penetration.

The approach to this problem that provides the lowest-risk development path and shortest development period is to identify and evaluate improvements to the existing fiber tube containers. Using that approach, a number of modifications to the existing container have been identified including 5 different types of container exterior coatings, an additional construction material in the container wall laminate, and 2 mechanical closure types. This document describes a testing program described in this conducted to provide a quantitative comparison of the moisture permeability of containers with these alternatives to the permeability of non-treated (without exterior coating) containers.

The test provides a format for quantitative comparison of variants of the current fiber tube container in terms of water/water-vapor absorption and transmission rate. The test plan was based on ASTM and MIL-STD standards to insure valid outcomes and repeatability. Water vapor permeability determination was based on ASTM D 1251-79, "Standard Test Method for Water Vapor Permeability of Packages by Cycle Method." In this paradigm packages containing a desiccant are exposed to hot temperature and humidity cycles and the weight of the package at the end of each cycle is recorded as a measure of the amount of moisture in the package. When the gross weight gain is plotted against the number of cycles, the slope of the line measures absorption and permeation per cycle of the package. Comparisons among packaging alternatives may be made on the basis of the slopes of the weight-gain trends. In the present experiment, this procedure was supplemented by separate weighing of the package and desiccant contained within the package to allow estimation of container wall absorption. The temperature-humidity profile followed MIL-STD-810E, aggravated temperature-humidity cycles (illustrated in Fig. 1). A subsidiary experiment evaluated the performance of the container variants after being resealed following initial opening.

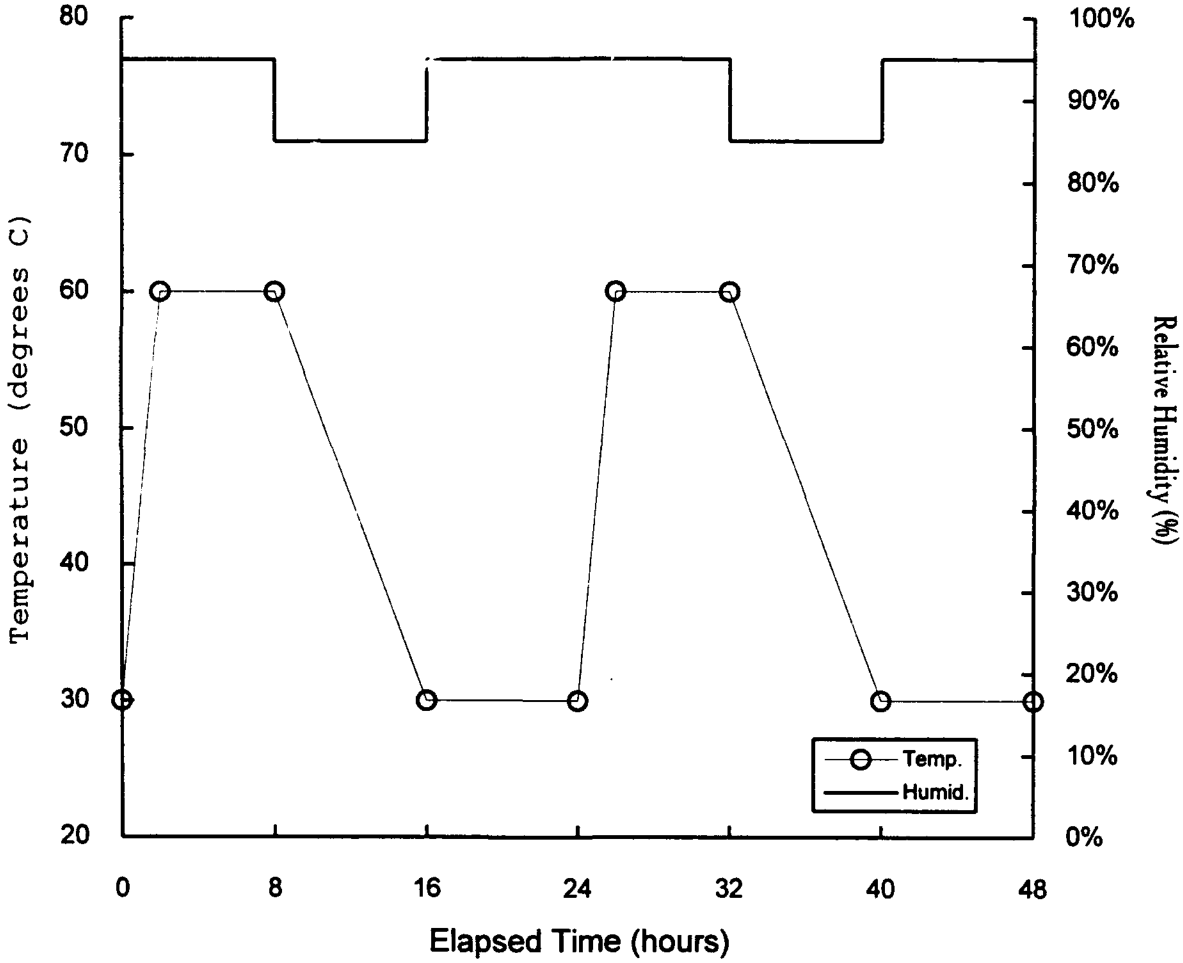

Figure 1. Two aggravated temperature-humidity cycles (from MIL-STD-810E, Figure 507.3.3.).

GENERAL INFORMATION

Test Duration and Location

The Packaging Division of U.S. Army Armament Research, Development, and Engineering Center (ARDEC) and the Robotics & Process Systems Division of Oak Ridge National Laboratory (ORNL) jointly planned and organized the test program and evaluated the test results. The comparative test was run at the Environmental Test Laboratory located at Building 60, Picatinny Arsenal, New Jersey, with the supervision and monitoring of ARDEC Packaging Division. The data collection took place between December 14, 1992, and February 17, 1993, over a total span of 65 days.

Equipment

Test Equipment

The equipment used to run the tests was as follows:

a. Environmental conditioning chamber (Fig. 2): Webber - Model WF-512.

b. Conditioning controller (Fig. 2): JC Systems - Model 520 Controller/Setpoint Programmer.

c. Weigh scale: Ohaus - Galaxy G4000-D0 (Precision: 0.0001 oz.).

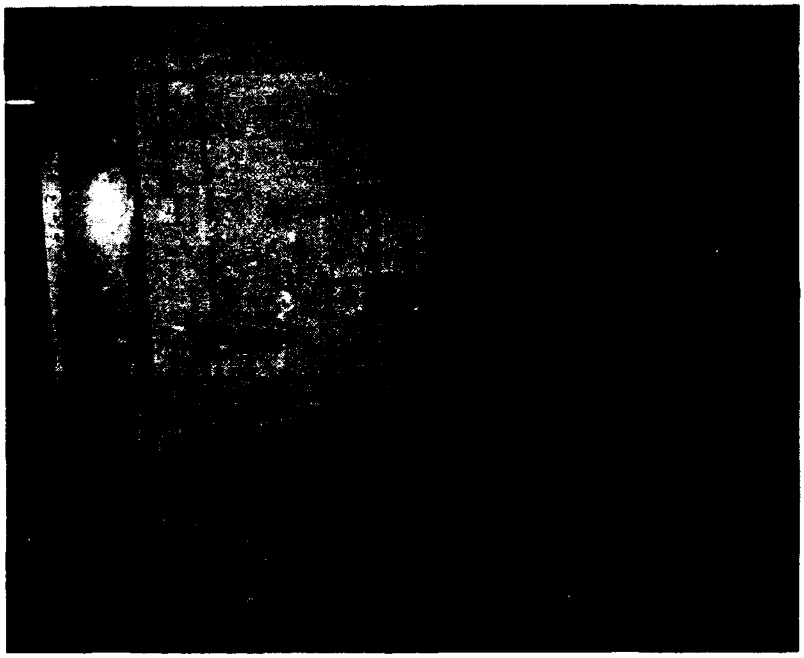

Figure 2. Weber WF-512 environmental chamber and JC Systems Model 520 controller.

Ammunition Fiber Containers

Thirteen variations on the 81 mm ammunition fiber container manufactured by United Ammunition Containers, Inc., Milan, Tennessee, were tested to examine their ability to resist permeation and absorption of moisture during hot and humid environment. The standard fiber containers were spirally wound in accordance with MIL-C-2439E, Type I, Class 2 with two layers of aluminum foil as moisture barrier and sealed using two layers of tape (MIL-T-43036, Type II and PPP-T-60, Type IV, Class 1). All the metal ends were double crimped. The container variants were as follows (note some exceptions to the standard container construction specification):

1) The outer layer of fiber was not treated with any coating. (Experiment ID: STDNON)

2) The outer layer of fiber was impregnated with wax (MIL-C-2439E, Type IV, Class 2). (Experiment ID: STDWAX)

3) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was not treated with any coating. (Experiment ID: LAMNON)

4) The outer layer of fiber was treated with "RABCO Cocoon 501" coating. (Experiment ID: STDCOC)

5) The outer layer of fiber was treated with "Ocean 2-Ply" coating. (Experiment ID: STDCOC)

6) The outer layer of fiber was treated with "UV Acrylate" coating. (Experiment ID: STDUVA)

7) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was not treated with any coating. The container was sealed using twist-on cuff type of closure mechanism. (Experiment ID: LTCH1)

8) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was not treated with any coating. The container was sealed using latch cuff type of closure mechanism. (Experiment ID: LTCH2)

9) The outer layer of fiber was treated with thin "Sol-Gel Ceramic" coating. (Experiment ID: STDCER)

10) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was treated with "RABCO Cocoon 501" coating. (Experiment ID" LAMCOC)

11) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was treated with "Ocean 2-Ply" coating. (Experiment ID: LAMOC2)

12) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was treated with "UV Acrylate" coating. (Experiment ID: LAMUV2)

13) The fiber container was wound with two layers of aluminum foil and two layers of plastic film as moisture barrier. The outer layer of fiber was treated with "Pyro Plus" coating. (Experiment ID:" LAMPYR)

To assure the reliability and validity of the test data, several representatives of each type were included in the test. This prevents the accident of a poorly constructed (and hence unrepresentative) container variant from skewing the data, as could happen if a single unit of each type was tested. Table 1 lists the number of containers of each type included in the test. Fig. 3 shows some of the ammunition containers inside the environmental chamber.

Desiccant Bags

The desiccant bags were manufactured by Englehard and were there model Desiccite 25, 1 unit, MIL-D-3464, Types I and II.

Container variant	Quantity	Specification
STDNON	20	Type I, Class 2, MIL-C-2439E
STDWAX	20	Type IV, Class 2, MIL-C-2439E
LAMNON	20	Similar to Type I, Class 2, MIL-C-2439E
STDCOC	20	Similar to Type I, Class 2, MIL-C-2439E
STDOC2	20	Similar to Type I, Class 2, MIL-C-2439E
STDUVA	20	Similar to Type I, Class 2, MIL-C-2439E
LTCH1	8	Similar to Type I, Class 2, MIL-C-2439E
LTCH2	8	Similar to Type I, Class 2, MIL-C-2439E
STDCER	3	Similar to Type I, Class 2, MIL-C-2439E
LAMCOC	5	Similar to Type I, Class 2, MIL-C-2439E
LAMOC2	5	Similar to Type I, Class 2, MIL-C-2439E
LAMUVA	5	Similar to Type I, Class 2, MIL-C-2439E
LAMPYR	5	Similar to Type I, Class 2, MIL-C-2439E

Table 1: Fiber container variants.

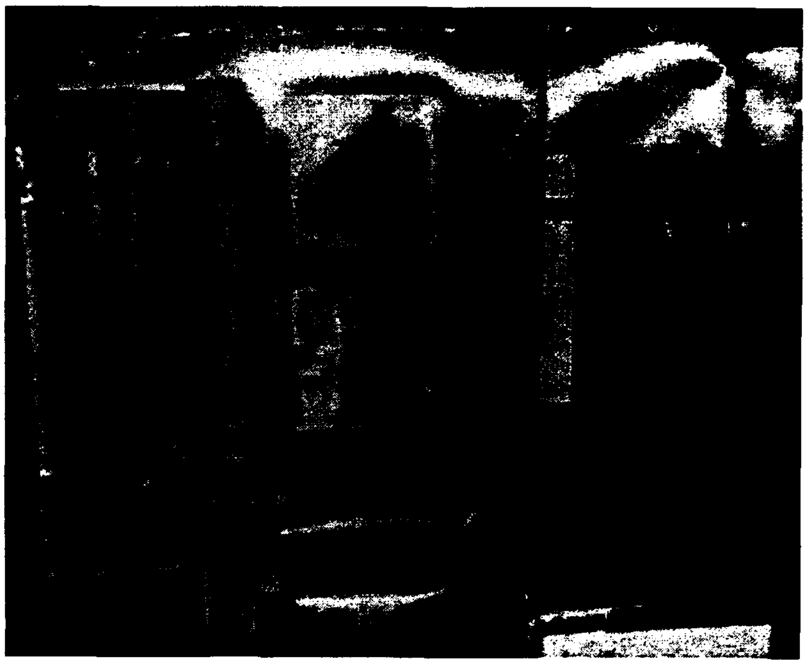

Figure 3. Ammunition containers within the environmental chamber.

PROCEDURES

Container Preparation

Prior to packing, the containers were placed in a temperature controlled environment at 90°F, 15%RH for 72 hours to minimize moisture in the container wall. The desiccant was reactivated by conditioning at 275°F for 24 hours prior to packing into the containers. Reactivated desiccant bags were weighed in lots of 5, inserted into a container (the container was weighed immediately before inserting the desiccant) and the container was sealed. No more than five minutes elapsed between weighing the desiccant and sealing the container. The containers were sealed using the standard two-tape seal (except for those with latches) including approximately twenty inches of sealing tape of each type (MIL-T-43036, Type II; and PPP-T-60, Type IV, Class 1). The sealed container was then weighed. The desiccant, container, and test specimen weights were recorded on a data sheet for the container.

Pre-conditioning and Conditioning

Conditioning of the test specimens was based on ASTM D 685-87 "Standard Method of Conditioning Paper and Paper Products for Testing." The purpose of this step was to minimize any humidity hysteresis effect, which could make measurements less accurate in the early stages of the experiment. This step began within one hour of initial weighing. The test specimens were placed in a test chamber and left in 20% relative humidity and 90°F for 24 hours. Without removing the test specimens from the test chamber, the chamber conditions were changed to 50% relative humidity and 75°F and held constant for 72 hours.

The test specimens were weighed immediately following conditioning and the pre-test weights were recorded on the data sheet. Two containers from each sample group were opened at this point and the desiccant bags removed, and the desiccant lot and container weighed. This allows determination of the amount of water absorbed by the containers and desiccant lot up to this point in the testing. The containers that were opened were re-packed with freshly-prepared desiccant bags, re-sealed, and re-inserted into the chamber.

Temperature-Humidity Cycle Exposure

Temperature-humidity cycling followed the pattern described in MIL-STD-810E and illustrated in Fig. 1. One temperature/humidity cycle lasted 24 hours: at the end of one cycle (24 hours), two cycles (48 hours), three cycles (72 hours), eight cycles (192 hours), fifteen cycles (360 hours), twenty-five cycles (600 hours), thirty cycles (720 hours), forty-three cycles (1032 hours), and sixty-five cycles (1560 hours) test specimens of each container/coating variant were removed from the test chamber, weighed, and then opened. After opening the container the desiccant bags and the container were weighed separately. The test specimen weight, container weight, and desiccant lot weight were recorded on the data sheet. Specified lots were re-packed with desiccant and reinserted into the test chamber for further cycling to test how well re-sealed containers perform. The twenty specimens with coatings applied to containers with plastic barrier and the test specimens designated for opening after 42 and 60 cycles were weighed each time that a specimen lot was removed from the test chamber. Test specimens with closure mechanisms were removed from the test chamber at the end of each cycle, weighed and opened, and the desiccant and container were weighed separately. Fresh desiccant packets were inserted into the containers, and the containers were closed, sealed, and re-inserted into the test chamber.

RESULTS

Test 1: Container Variants

Fig. 4 illustrates the trend of weight gain averages with temperature/humidity cycles for each container coating and construction variant (the ceramic-coated standard container is not included on the graph because it gained weight so rapidly). (The points in Fig. 4 and following figures represent averages of the total number of containers of a particular variant available.) From the figure, it appears that the variants may be ordered into three sets: a "best" group including the current standard, wax-impregnated container and the un-coated, laminate-construction container; a "good" group including the standard container with the Ocean Coatings 2-ply coating, the UV-acrylate, and with the RABCO Cocoon. All of the coating and construction variants performed better than the un-coated, standard-construction fiber tube.

The raw data for each container variant were submitted to a linear regression analysis to determine the best-fit line relating cumulative weight gain to the number of temperature/humidity cycles, using least-squares equations. The linear regression coefficients for each variant are listed in Table 2. Within the table, tne first column gives the container variant, the second column gives the intercept of the line (the weight change after conditioning), the third column gives the slope of the line (this is the critical index, the weight change for each temperature/humidity cycle), and the third column gives a measure of the performance of the statistical model called R^2. The R^2 index measures how much of the variability in a dependant variable is accounted for by the regression model (and hence the descriptive power of the model) and it ranges from 0 (no descriptive power) to 1 (perfect descriptive power). From the table, it seems that for most of the variants the equations had very strong power: the exception was the set treated

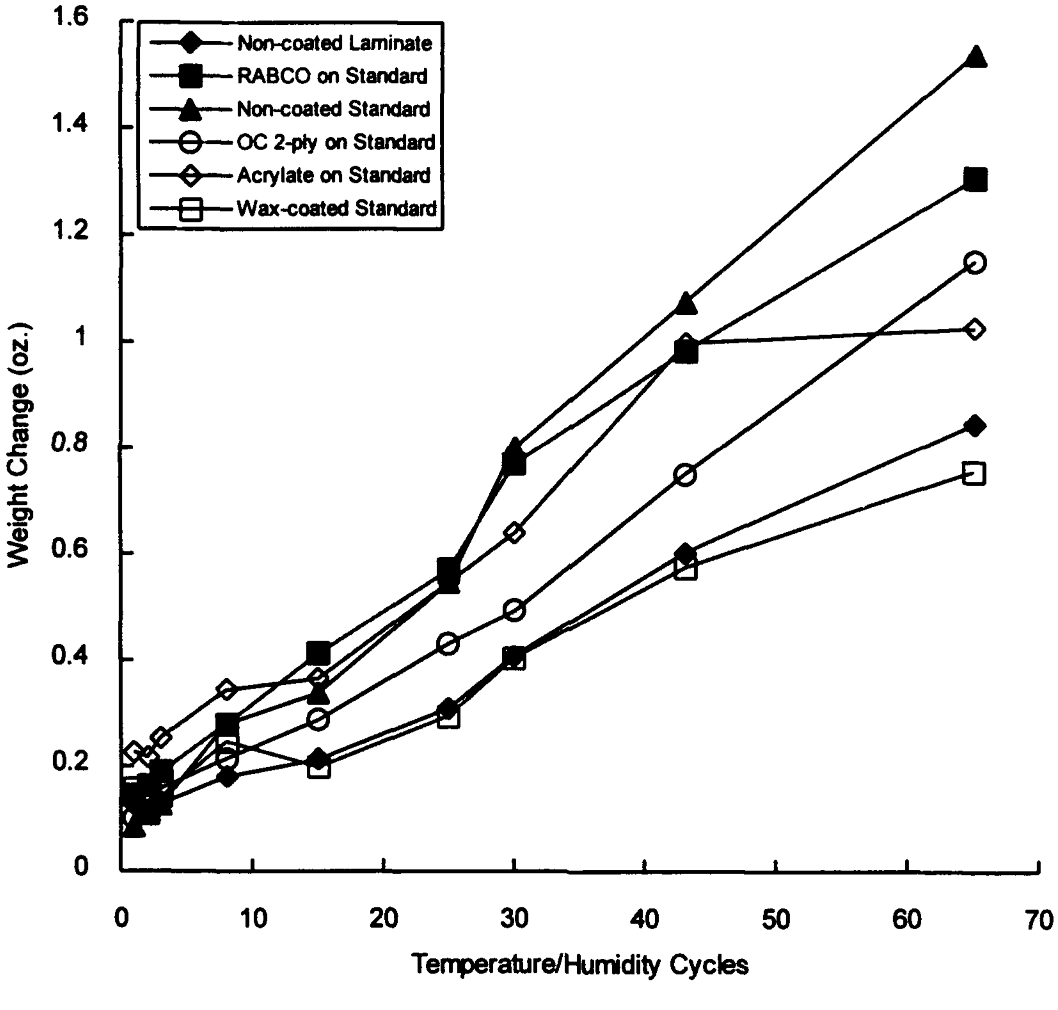

Figure 4. Weight gain for each temperature/humidity cycle.

Container variant	Intercept	Slope	R^2
Non-treated containers with 2 layers of aluminum barrier	0.047	0.025	0.94
Wax-impregnated containers with 2 layers of alum. barrier	0.097	0.010	0.86
Non-treated containers with 2 layers of plastic barrier and aluminum foil	0.075	0.011	0.85
Containers treated with "RABCO Cocoon 501" coating	0.110	0.020	0.94
Containers treated with "Ocean Coatings	0.072	0.017	0.87
Containers treated with "UV Acrylate" coating	0.167	0.016	0.51
Containers treated with thin ceramic coating (STDCER)	0.953	0.123	0.95

Table 2. Regression equation parameters for each container variant.

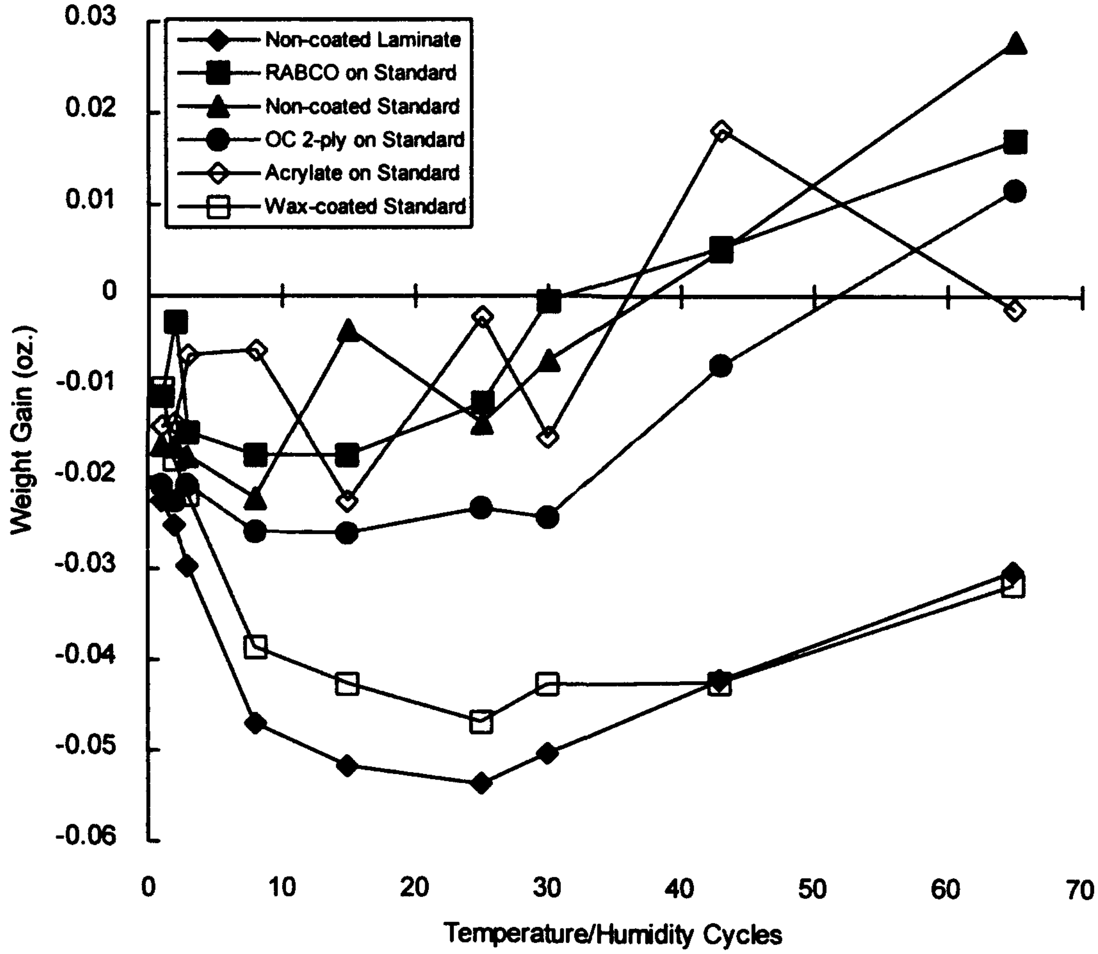

Figure 5. Container weight gain.

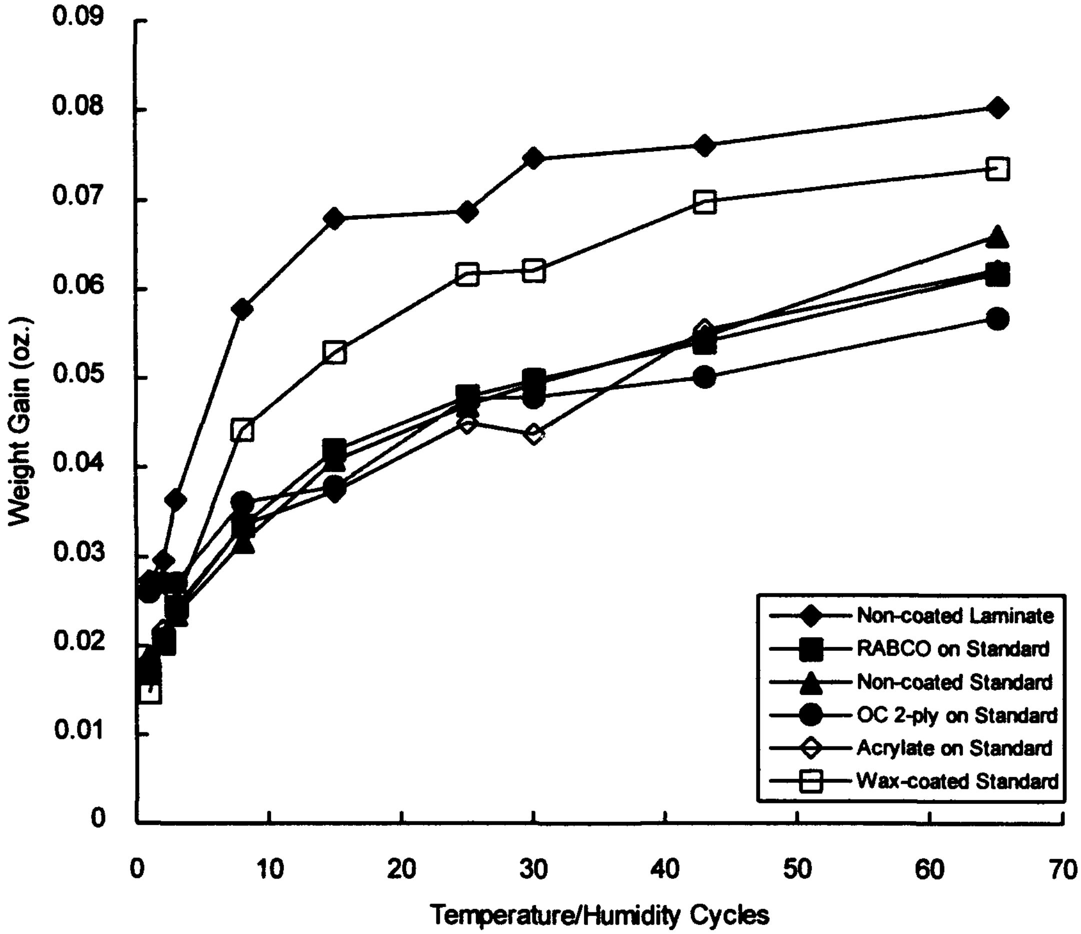

Figure 6. Desiccant weight gain.

with UV acrylate, which with R^2=0.51 has moderate power. The slopes listed in Table 2 give further evidence in support of the observations from Figure 4: the containers with plastic barrier and the standard, wax-impregnated containers have the lowest slopes and are not very different from each other. These two variants provided the best protection from moisture during the temperature/humidity cycles.

Figures 5 and 6 show the average weight gain for containers and desiccant, respectively. The trends these figures illustrate are interesting: the container weight for the best group fell during the first 10 temperature/humidity cycles and then was fairly stable until the 25th cycle, when it started to increase. For the other variants an initial weight loss was followed by a trend towards increasing weight starting after 8 cycles and continuing throughout the remainder of the experiment. On the other hand, desiccant weight increased at a rapid pace during the first 10 to 20 temperature humidity cycles and then increased more gradually through the remainder of the experiment. Desiccant gain was highest for the variants in the best group.

These trends are evidence that early on, for the containers in the best group (wax-impregnated and uncoated, laminate construction containers) moisture was either drawn (1) into the container wall at a slower rate than it was drawn from the container wall, or (2) into the container through the end-cap seals or the neck seal but not absorbed through the container wall. The evidence for this interpretation is the sharp desiccant weight increase accompanied by (1) increasing specimen weight and (2) decreasing container weight. Moisture was penetrating the container or the specimen weight could not increase; however, if moisture was permeating the container wall some absorption should have been observed as container weight gain, but in fact the container weight decreased, indicating that it was drying out. The steady concurrent gain in container and desiccant weight for the other containers is evidence that moisture penetrated the container wall and reached the desiccant while at the same time some was absorbed by the container. The containers not in the best group may not have been able to maintain a sharp enough moisture gradient to induce penetration around the end caps or neck seal. This would explain why the desiccant gain trend asymptotes in the best group: after sufficient moisture was absorbed by the desiccant to narrow the moisture gradient, penetration through the end caps and neck seal ceased. The desiccant absorbed very little moisture after this point was reached, but the long exposure led to some absorption by the container, as evidenced by the container weight gain in the best group after 25 cycles.

Test 2: Latches

Figure 7 shows the average weight gain for each of two latch variants and for the two variants from the best group identified in the first experiment. Table 3 shows the regression coefficients for each variant. From the figure, it appears that the latches did not have a consistent impact on container performance and this is reflected in the low R^2 listed in Table 3 for the two latch types. During the testing cuff/closure modification No. 2 (latch) proved much easier to operate than modification No. 1 (twist-on). The twist-on closure was very difficult to seal properly, usually requiring the use of pliers or a vise-grip and the mechanism frequently became bent out of shape and required repair. Figure 8 and Figure 9 are photographs of a latch-type cuff/closure modification. In the version in the photographs the cuff is a narrow steel ring and the latches are attached to it by tabs. This design was rejected because the tabs tended to pull away from the body of the tube, so the version used in the testing had a steel ring extending from the lip of the container all the way out to the edge of the tabs.

Test 3: Coatings on Laminate-Construction Containers

Containers coated with Pyro Plus exhibited blistering, peeling, and running and were not included in the data analysis because of their obvious unsuitability. Figure 10 shows the impact of the other coating options on the performance of laminate-construction containers and Table 3 lists the regression coefficients. From the figure, it appears that all of the coatings had a positive effect but the Ocean Coatings 2-ply and the UV Acrylate coatings had the greatest impact, both with slopes of 0.008. The UV Acrylate appeared to have the most stable performance of the two, with an $R^2 = 0.96$.

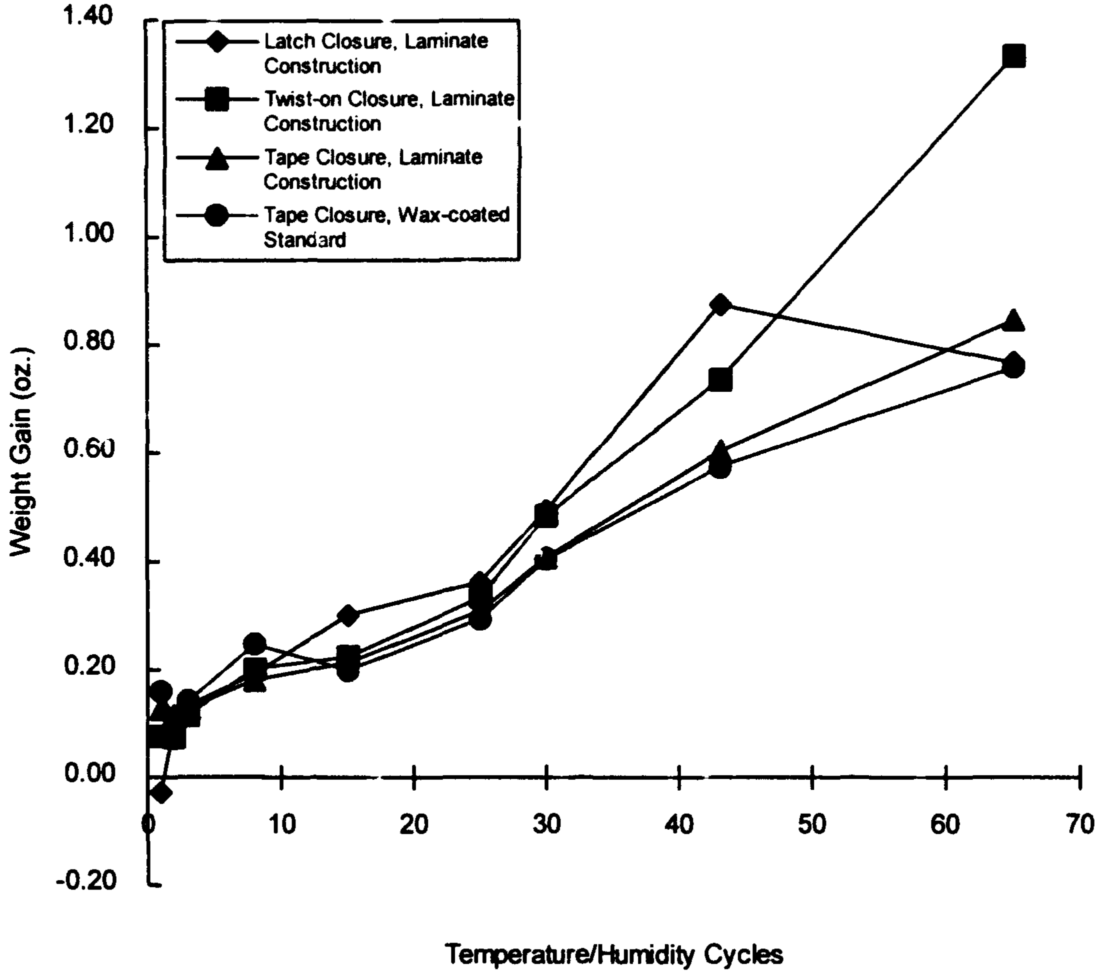

Figure 7. Effects of closures on weight gain.

Container variant	Intercept	Slope	R^2
Non-treated containers with 2 layers of plastic barrier and aluminum foil	0.075	0.011	0.85
Wax-impregnated containers with 2 layers of alum. barrier	0.097	0.010	0.86
Containers with plastic barrier and cuff/closure modification No. 1 (twist-on)	0.052	0.025	0.74
Containers with plastic barrier and cuff/closure modification No. 2 (latch)	0.051	0.018	0.87

Table 3. Regression equation parameters for containers with closures.

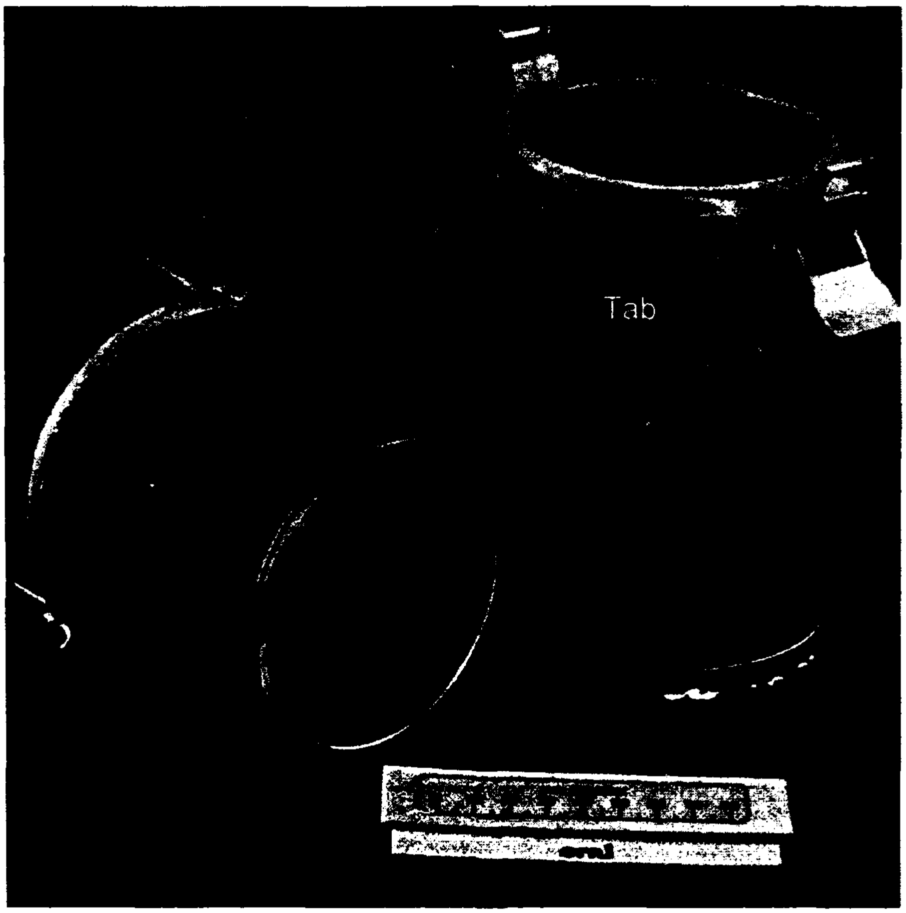

Figure 8. Latch-type cuff/closure, open.

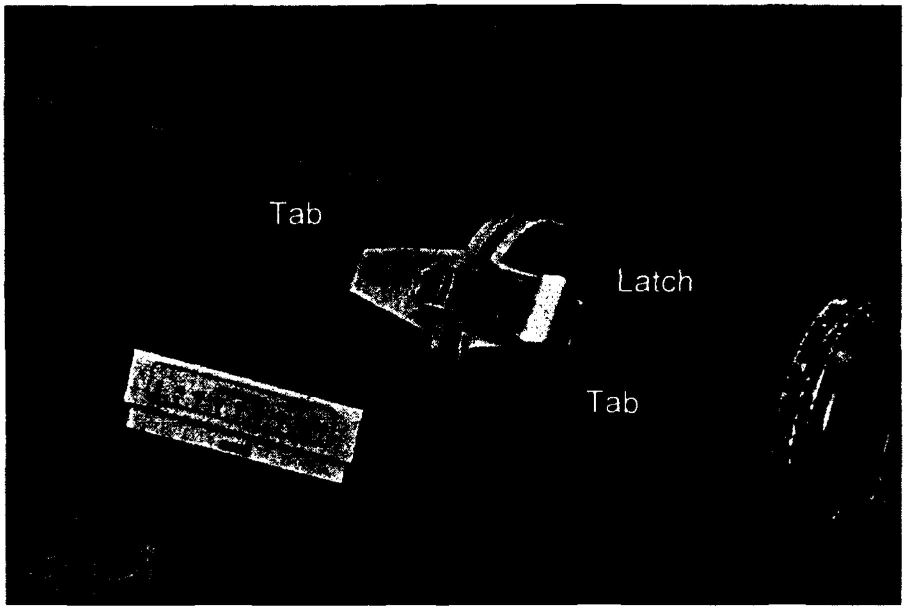

Figure 9. Latch-type cuff/closure, closed.

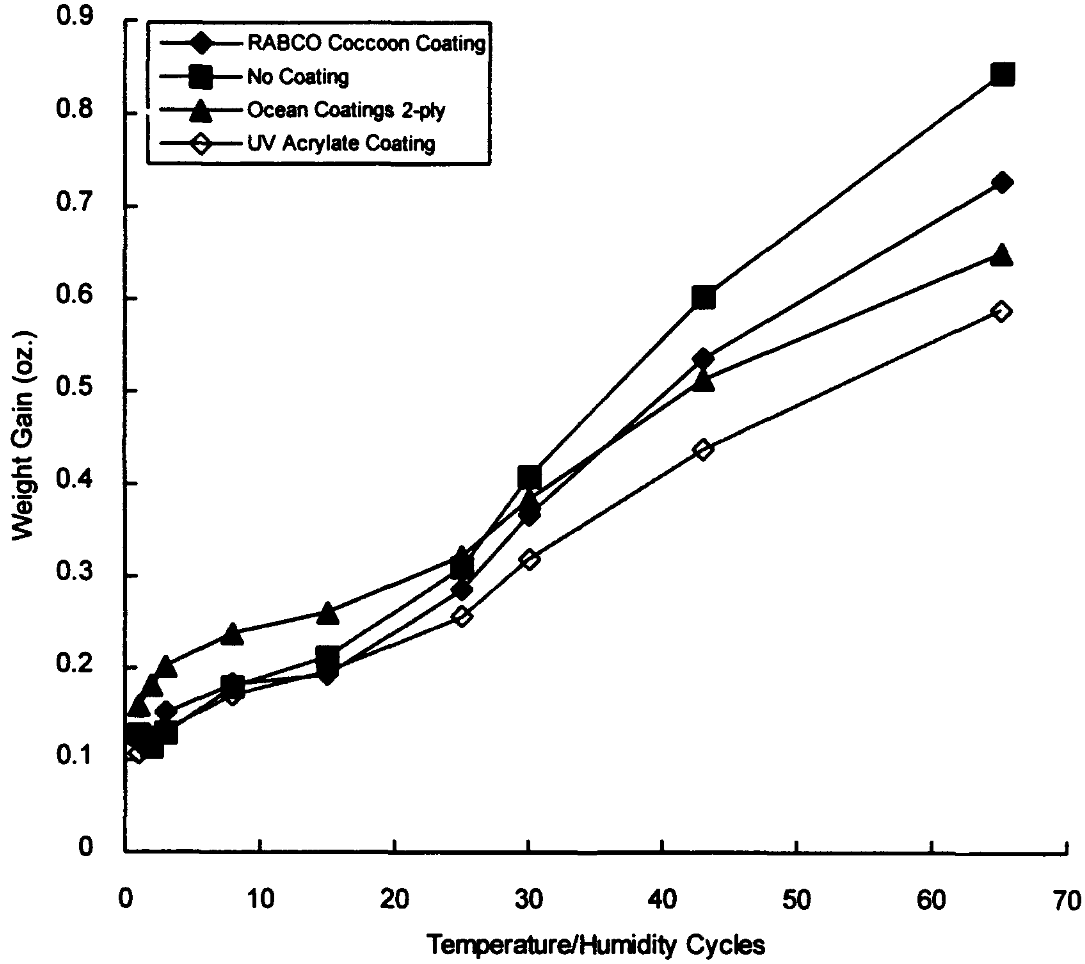

Figure 10. Weight gain for coated, laminate-construction container variants.

Container variant	Intercept	Slope	R^2
Non-treated containers with 2 layers of plastic barrier and aluminum foil	0.075	0.011	0.85
Wax-impregnated containers with 2 layers of alum. barrier	0.097	0.010	0.86
Containers with plastic barrier and "Ocean Coatings 2-ply" coating	0.150	0.008	0.64
Containers with plastic barrier and "UV Acrylate" coating	0.088	0.008	0.96

Table 4. Regression equation parameters for each container coating on laminate-construction fiber tubes.

Test Observations

At the end of the 65 aggravated temperature-humidity cycles, it was observed that all the 13 types of existing/improved containers were overall in sound conditions with some wrinkles in the sealing tape (PPP-T-60). No structural problems due to moisture absorption and penetration were found. Additional observations were as follows:

1. STDNON — Considerable amount of winkles appeared on the container wall. Minor corrosion was also observed on the metal end plates.

2. STDWAX — Minor winkles appeared on the container wall. The sealing tapes (PPP-T-60) were falling apart from the container walls because of the incompatibility of the wax and the adhesive material.

3. LAMNON — Considerable amount of winkles appeared on the container wall. Minor corrosion was also observed on the metal end plates.

4. STDCOC — Coating peeled off and separated from the container wall.

5. STDOC2 — Minor winkles appeared on the container wall. Affected by the coating, the color of the container wall faded and degraded from black to blue and purple.

6. STDUVA — Minor winkles appeared on the container wall. Considerable amount of coating peeled off and blistered on some areas and spots. Corrosion was also observed on the metal end plates.

7. LTCH1 — Considerable amount of winkles appeared on the container wall. Severe corrosion took place on the non-painted metal closure.

8. LTCH2 — Considerable amount of winkles appeared on the container wall. Severe corrosion took place on the non-painted metal closure.

9. STDCER — The containers that absorbed a lot of moisture irregularly warped, swelled, and distorted. The container covers were not able to be opened due

to deformation and distortion. Furthermore, the end metal plates severely corroded caused by the coating.

10. LAMCOC — Coating peeled off and separated from the container wall.

11. LAMOC2 — Minor winkles appeared on the container wall. The color of the bottom part of container wall faded and degraded from light brown to grey affected by the coating.

12. LAMUVA — Minor winkles appeared on the container wall. Considerable amount of coating peeled off and blistered on some areas.

13. LAMPYR — Coating severely peeled off, blistered, and separated from the container wall.

Test 4: Re-Sealing

After the containers were opened, they were packed with fresh desiccant, resealed with fresh tape, and returned to the environmental chamber to evaluate how well each variant performed after being resealed. The results indicated that none of the coatings demonstrated good reseal performance. However, the laminate construction and wax-impregnated containers performed the best.

CONCLUSIONS

While the test data demonstrate that the existing military standard wax-impregnated ammunition container performed well, it also shows that an alternative, the laminate-construction container, performed at least as well. Furthermore, the outside layer of the laminate-construction container was not protected from moisture and this may have contributed to total container weight gain; because the wax impregnation protected the outer layer of the STDWAX container, it was not prone to weight gain from this source. The performance of a laminate-construction container with moisture protection coating on the outer layer of fiber should be even better. The data also demonstrate that a laminate-construction container with UV acrylate coating or Ocean Coatings 2-ply performed better than the unwaxed container, which may be evidence that protecting the outer layer from moisture improves laminate-construction container performance. It is also worth noting that the tape seal used in the experiment is optimal for all the kinds of containers except for wax-coated containers. Sealing tape optimized for the coatings could further improve performance by reducing moisture intrusion around the seal. However, from the fourth experiment there do not appear to be differences among coatings after resealing, so the tape may work as well for one as the other.

Containers with latching mechanisms did not perform as well as containers with tape seals, but the performance of the latched containers was more variable. The poor performance and the variability were probably caused by imperfections in latch constructions and differences in experimental procedures. The latched containers were opened and the desiccant was replaced more often than for the taped containers, providing the latched containers with typically higher humidity gradients. The latches themselves also contributed to the weight gain because they rusted.

The purpose of this test was to identify container variants worth further development and those which should be dropped from further consideration. It appears that none of the proposed coatings performed better than the wax-impregnated containers currently in use and most proved unsatisfactory.

The twist-on closure should not be considered further because of inferior sealing and difficult operation. Performance of the thin-film ceramic coating also warrants dropping it from consideration.

Taken together, these data summarized in table 5 demonstrate that a container built on the plastic laminate model and coated with a moisture-resistant outer barrier would provide superior performance to the existing container. A logical next step would be to build a representative sample that is mass producible and conduct a further comparison using the methods described in this document. It would not be necessary to test further examples of the military standard; data from the new pattern container could be compared to existing data from the current military standard container.

RECOMMENDATION

Based on the results of the comparative tests, it appears that a painted container with plastic laminated barrier construction sealed with latching system could be the best solution to the problem. It is recommended that further study in the area of top paint ~~continue~~ coating and container producibility be pursued in order to develop the new generation of packaging for mortar ammunition.

Standard (with Aluminum Barrier)		Standard with extra Plastic Barrier	
Wax	0.7568		
		Pyro Plus	0.4771
UV Acrylate	1.0256	UV Acrylate	0.5894
Ocean 2-ply	1.152	Ocean 2-ply	0.6506
RABCO	1.3056	RABCO	0.7277
		Latch Closure	0.766
Non-coated	1.5392	Non-coated	0.8448
		Twist-on	1.3324
Ceramic	8.1056		

Table 5. Average weight gain of each type of container after 65 environmental test cycles (oz)

DISTRIBUTION LIST

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