

AMERICAN WOOD PROTECTION ASSOCIATION

Continued Evaluation of Mold Treatments for Wood Based Military Packaging in Storage

Rachel Arango

Grant Kirker

Katie Ohno

Amy Bishell

Patrick Dewald

Forest Products Laboratory, Madison, WI
Picatinny Arsenal, NJ

ABSTRACT

The U.S. Army depends heavily on wood packaging materials (WPMs) for the storage and transport of ammunition, yet these materials are highly susceptible to mold growth under the damp, poorly ventilated conditions of the buildings used for storage. Despite wooden ammunition boxes being treated to military specifications, mold growth persists and, therefore, there is a need for improved evaluation methods for mold prevention. This project adapted the full-size commodity termite test (AWPA E21-18) into a field-based mold exposure setup. It was intended to replicate the high-moisture conditions in military earthen bunkers where WPMs on pallets are stored directly on concrete but at a smaller scale. This approach provides a means to assess wood treatments and moldicide additives off-site with the intent to improve durability and performance of military WPMs.

Keywords: wood-based packaging, mold, E21 field test, wood treatments, durability

INTRODUCTION

Military wood packaging materials (WPMs) for shipping munitions are expected to have a useful life of two or more years under outdoor exposure and up to twenty years when stored indoors. They are expected to maintain structural integrity and cleanliness over this period. To achieve this, WPMs are dip treated with a variety of military approved wood preservatives and stored in military earthen bunkers. The Forest Products Laboratory has been assisting with evaluation and selection of wood preservatives for protecting military WPMs for decades (DeGroot and Stroukoff 1986; Lebow et al. 2017; U.S. Army 2017a,b). Three water-based preservatives, zinc naphthenate (ZnN), copper naphthenate (CuN), and copper-8-quinolinolate (Cu8), were found to be equivalent or better than the standard reference treatment (i.e., 5% oil-based pentachlorophenol) in resisting decay. All three were subsequently incorporated into DOD specifications and various formulations of these three main preservatives were allowed for use in treating WPMs (Lebow et al. 2015).

However, these preservative formulations were aimed at protecting against wood decay fungi and termites as these are the most likely to cause structural damage to WPMs with little attention paid to prevention of mold fungi. Wood packing materials are housed for long periods of time in earthen bunkers under conditions that are favorable for mold growth due to high moisture and limited to no ventilation. In addition, pallets are stored in direct contact with concrete, which has the potential for absorbing and retaining moisture (Fig. 1). These environmental conditions create ideal circumstances for mold colonization, which can stain WPMs and potentially interfere with identification markings, handling, or overall serviceability.

AMERICAN WOOD PROTECTION ASSOCIATION



Figure 1. Wire-bound boxes on shipping pallet with substantial mold growth.

Since 2011, military depot personnel have noted increasing instances of mold growth on WPMs in storage. To address this issue, Arango et al. (2023) evaluated moldicidal additives to be used with primary wood preservatives. While these new formulations are currently being used in dip-treatments, many of the WPMs stored in earthen bunkers remain susceptible to mold growth. This project focused on developing a field test setup intended to simulate mold-inducing environmental conditions like those of military earthen bunkers. The goal was to create a method applicable for screening mold resistant treatments for WPMs under storage conditions. The field setup intended to promote mold growth with elevated temperature and elevated moisture.

Smaller scale wood specimens were used following the AWWA E21-18 standard. Ground proximity test frames were modified and adapted for the project to create a field mold box test. These enclosures allowed for increased humidity and limited airflow, similar to that found in earthen bunkers. Overall, this project provides a framework for evaluating mold resistant treatments for WPMs that could be installed at any field site in the US. These results will support improved treatment selection, better durability of ammunition packaging, and more reliable long term storage performance in challenging environments.

MATERIALS AND METHODS

Southern pine (SYP), hardwood plywood (HP) and softwood plywood (SP) test specimens (20 x 70 x 7 mm) were selected as wood materials to represent WPMs. Test specimens were dipped for one minute in various treatments including aqueous copper 8 quinolinolate (Cu8), aqueous copper naphthenate (CuN), aqueous copper naphthenate + didecyldimethyl ammonium chloride (DDAC-Cl) (CuN+), aqueous azole + imidacloprid (AZI), aqueous azole + imidacloprid + didecyldimethyl ammonium carbonate (DDAC-Carb) (AZI+) or water. Specimens were air dry in a chemical hood following dip treatment. Mini wood pallets consisting of six untreated solid red oak specimens (70 x 20 x 7 mm each) held together by metal staples were made to represent a basic military shipping pallet. All treated test specimens were attached (with a center nail) to mini wood pallets with SP on the left, SYP in the center, and HP on the right (Fig. 2).

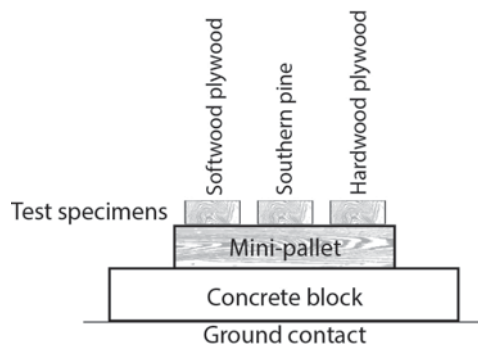


Figure 2. Schematic representation of mini pallet configuration used in this study.

AMERICAN WOOD PROTECTION ASSOCIATION

Five box covers (AWPA E21-18) consisting of painted plywood panels were made to house the mini test pallets that measured 48.3 cm long x 16 cm wide x 11 or 12 cm tall (slanted roof). Front and back panels had two 2.5 cm diameter holes covered with a mesh for ventilation. These fit a total of 25 mini-pallets under each box with various wood combinations and treatments. Mini pallets with attached treated specimens were placed in the field directly on a concrete slab and then covered with the white box cover as shown in Figure 3. Temperature and humidity within each box were monitored using HOBO Data Loggers (MX2300).



Figure 3. Valley view test plot (M24-01). Boxes covering test specimens (left) and uncovered mini-pallet test specimens (right).

Test specimens were installed in Madison, WI, USA (Valley View Test Site) at the end of August 2024. Monthly visual ratings of specimens and pallets were initiated after 7 months in the field (first signs of growth). Visual ratings followed a 0-5 scale based on the growth/coverage where 0 is no mold growth and 5 is mold growth across the entire surface (AWPA E24-21). At 12 months, an aesthetic rating system as described in Arango et al. (2020 & 2023) was determined from photographs. Results presented in this study are average coverage and aesthetic mold growth ratings after 12 months of field exposure.

RESULTS AND DISCUSSION

Temperature and relative humidity (RH) data recorded from inside the test boxes over the rating period is shown in Figure 4. This data suggests that even during colder months, RH remained relatively high, which helped to support continued mold growth. After 12 months of field exposure, nearly all pallets rated 5 (fully covered by mold). This demonstrated that the mini mold boxes could replicate the high mold environment of earthen bunkers with enough inoculum to accurately test potential mold inhibitors.

AMERICAN WOOD PROTECTION ASSOCIATION

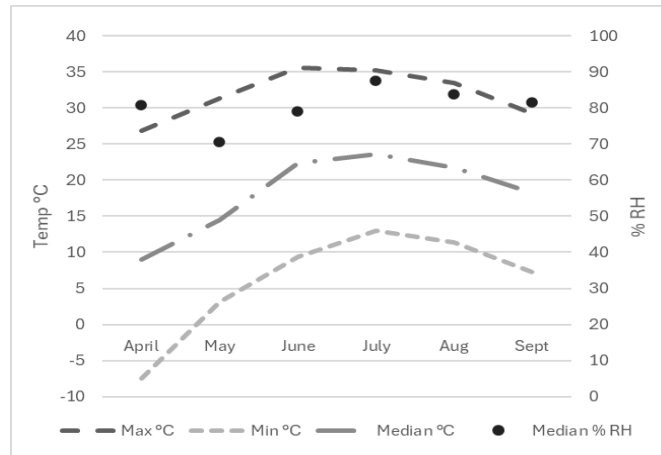


Figure 4. Temperature and RH data from HOBOT data loggers inside of AWP E21-18 boxes.

Treated wood samples showed varying amounts of mold growth depending on wood treatment (Figs. 5 & 6). Early results show Cu8 and AZI have comparable mold growth to the untreated controls. However, AZI with a co-biocide had lower mold growth. Copper naphthenate with and without co-biocide was similarly effective at inhibiting mold growth. These results indicate that the newer preservative formulations (with a co-biocide) as shown in Arango et al. (2023) should provide improved mold resistance on WPMs in storage going forward but that materials without a co-biocide may be more susceptible to mold.

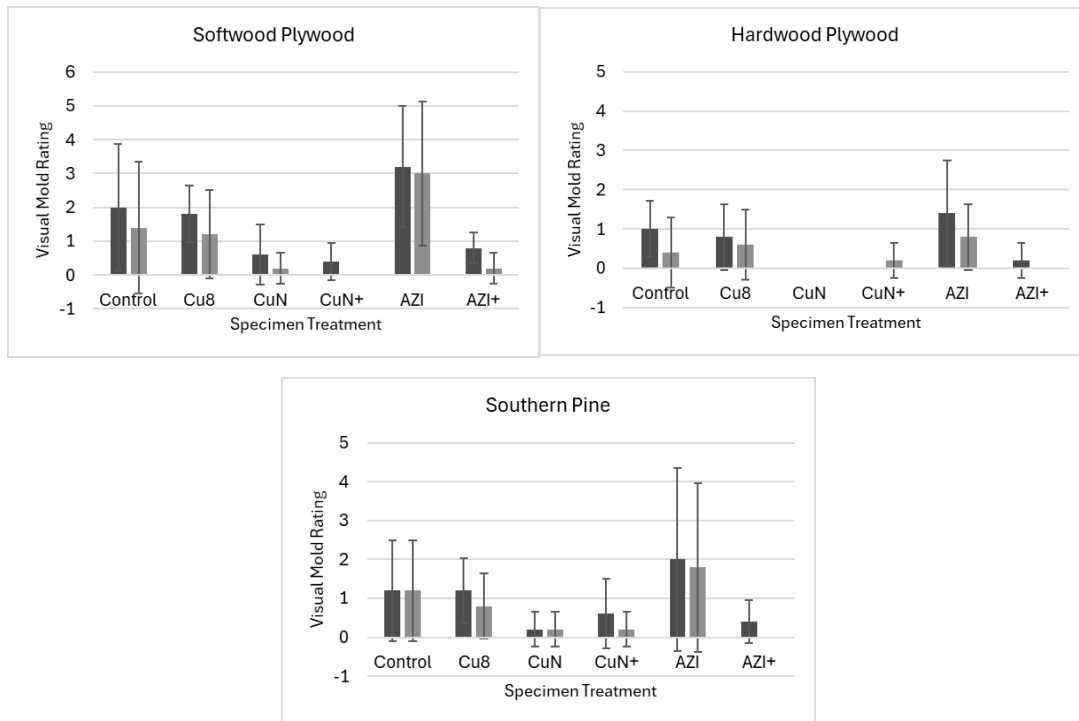


Figure 5. Average coverage (dark grey) and aesthetic (light grey) mold growth ratings after 12 months of field exposure.

AMERICAN WOOD PROTECTION ASSOCIATION

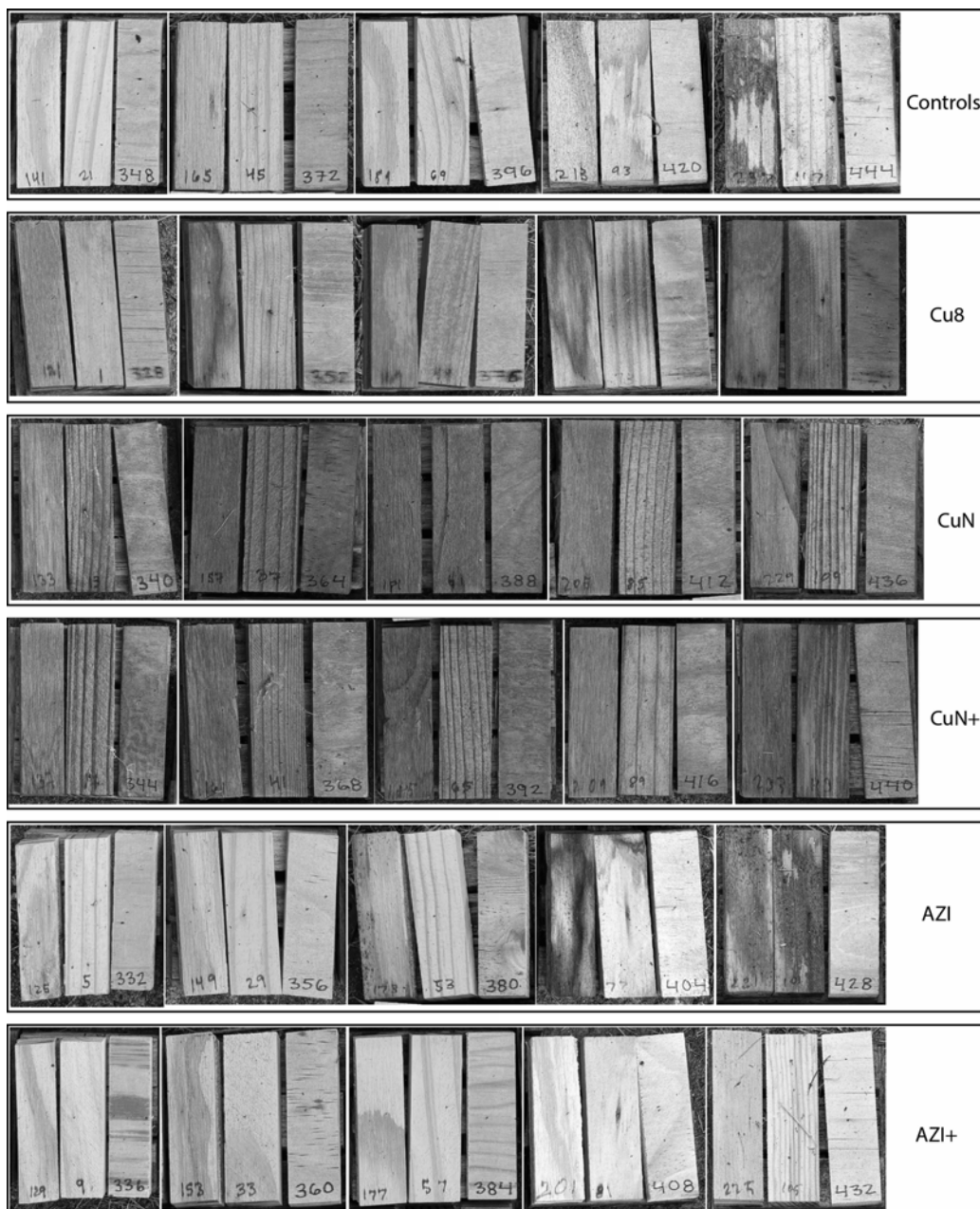


Figure 6. Mold growth on test specimens nailed to mini pallets after 12 months of field exposure.

In terms of overall mold growth, results showed a high degree of variability across samples suggesting that several environmental and substrate related factors likely influenced the outcomes. High moisture levels present during exposure created conditions favorable for mold development, while water bridging caused by direct physical contact with concrete surfaces likely accelerated moisture transfer into the wood. This was seen in two of the test boxes that frequently had standing water accumulation near but not directly under the boxes which resulted in higher mold growth on both treated and control specimens. Here, the water solubility of the treatment chemicals, combined with the absence of a sealant, may have limited the persistence and effectiveness of the active ingredients of the chemical treatment over time. Additionally, the relatively low uptake of active ingredients in the wood treated by a one-minute dip likely contributed to reduced performance consistency. Taken together, these factors highlight the complexity of

AMERICAN WOOD PROTECTION ASSOCIATION

treatment efficacy under real world conditions and underscore the importance of application method, formulation stability, and environmental exposure in determining mold resistance.

CONCLUSION

The results of this study demonstrate that the modified AWPA E21-18 box configuration is a practical and effective tool for conducting mold resistance testing of WPMs used in military supply chains. The setup reproduced mold growth patterns consistent with those observed in military earthen bunkers. This supports its value as a screening method for evaluating treatments, wood-based materials, and potential remedial strategies without requiring repeated access to in-service military sites.

A key observation of this study was concrete derived moisture, capillary water bridging upward into wooden components, as a potential driver of mold development. Additionally, the modified AWPA E21-18 box configuration provided at least 70% RH throughout the course of the study. This aligns with the persistent mold problems reported in military earthen bunkers, where high humidity and poor ventilation contribute to the problem. Pallets in direct contact with the concrete readily molded to the highest rating and served as a steady stream of inoculum to the treated test specimens. This provided sufficient moisture for mold development even when wood materials were treated according to military specifications.

These findings highlight the importance of moisture management within military earthen bunkers. Additional chemical treatment alone cannot compensate for continuous wetting from capillary mechanisms along with high humidity and low ventilation that maintain wood moisture levels well above the threshold at which mold becomes active. As a result, physical buffers aimed at disrupting the moisture pathway, such as barriers, risers, coatings, or isolation layers between wood packaging and concrete, represent a potential strategy for mitigating mold risk in the future. Prioritizing moisture interruption over additional pallet treatments will likely provide the most significant benefit to the longevity, cleanliness, and performance of wood packaging materials in military earthen bunkers.

FUTURE WORK

Physical spacing and pallet barriers

Because capillary moisture transfer from concrete was identified as a primary driver of mold growth, introducing physical spacing between wood packaging and the concrete represents a promising mitigation strategy. Barriers such as polymer sheets, raised platforms, coatings or waxes can interrupt the capillary pathway and significantly reduce moisture uptake. Wax-based coatings can slow wetting rates, protect end-grain surfaces, and create a partial vapor barrier without significantly altering the dimensional or mechanical properties of the wood. Evaluating options for durability, load-bearing capacity, compatibility with ammunition handling requirements, and ease of deployment in bunker environments will be important for operational adoption.

Continue to evaluate treatment additives

While moisture control remains the most critical factor, the role of chemical additives in reducing mold susceptibility still warrants exploration. Additives with moldicidal properties may enhance the performance of standard dip-treatment formulations currently in-use. Laboratory screening would provide complementary analysis of candidate chemistries before transitioning to the modified E21 box configuration field trials. Future research should focus on identifying additives that balance efficacy, regulatory compliance, environmental compatibility, and long-term durability.

ACKNOWLEDGEMENTS

This work was supported in part by a Military Interdepartmental Purchase Request (MIPR) agreement number 25-IA-1111136-004. The authors thank Craig Bell for design and fabrication of the mold boxes and Elias Glass for assistance in specimen preparation. Mention of trade names or specific products do not imply endorsement by the US Forest Service, Forest Products Laboratory and are for informational purposes only.

AMERICAN WOOD PROTECTION ASSOCIATION

REFERENCES

- Arango, R.A., V. Yang, S. Lebow, P. Lebow, M. Wiemann, M. Grejczyk, and P. DeWald. 2020. Variation in mold susceptibility among hardwood species under laboratory conditions. *International Biodeterioration & Biodegradation*, 154: 105082.
- Arango, R.A., S.T. Lebow, V. Yang, S.L. Zelinka, P.K. Lebow, and P. DeWald. 2023. Evaluation of moldicidal additives for wood preservatives used in dip-treatment of wood packing materials for military applications. U.S. Department of Agriculture, Forest Products Laboratory, Madison, WI, FPL-RP-715, 41 p.
- American Wood Protection Association. 2026. Standard Field Test for Evaluation of Wood Preservatives to be used for Interior Applications (UC1 and UC2); Full-Size Commodity Termite Test. Standard E21-18. Book of Standards. AWP, Birmingham, AL, pp. 487-491.
- American Wood Protection Association. 2026. Laboratory Method for Evaluating the Mold Resistance of Wood-based Materials: Mold Chamber Test. Standard E24-21. Book of Standards. AWP, Birmingham, AL, pp. 504-508.
- DeGroot, R.C. and Stroukoff, M., 1986. Efficacy of alternative preservatives used in dip treatments for wood boxes. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI. FPL-RP-481.
- Lebow, S., R. Arango, B. Woodward, P. Lebow, and K. Ohno. 2015. Efficacy of alternatives to zinc naphthenate for dip treatment of wood packaging materials. *International Biodeterioration & Biodegradation*, 104: 371-376.
- Lebow, S.T., S.L. Zelinka, R.A. Arango, B.M. Woodward, P.K. Lebow, K.M. Ohno, and N.P. Chotlos. 2017. Evaluation of nonpressure wood preservatives for military applications. U.S. Department of Agriculture, Forest Products Laboratory, Madison, WI, FPL-RP-693, 32 p. <https://doi.org/10.2737/FPL-RP-693>
- U.S. Army. 2017a. Drawing 13060578. Preservative, Wood. U.S. Army Armament Research, Development and Engineering Center (ARDEC). Rockaway Township, NJ: Picatinny Arsenal: 3p.
- U.S. Army. 2017b. Drawing 13064136. Wood packing material, preservative treated. U.S. Army Armament Research, Development and Engineering Center (ARDEC). Rockaway Township, NJ: Picatinny Arsenal: 26 p.