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The Need for Performance Criteria in Evaluating the Durability of Wood Products

Stan Lebow[1*], Bessie Woodward[1], Patricia Lebow[1] and Carol Clausen[1]

[1]USDA, Forest Service, Forest Products Laboratory Madison, Wisconsin, USA

[*]E-mail: slebow@fsfed.us

Abstract

Data generated from wood-product durability evaluations can be difficult to interpret. Standard methods used to evaluate the potential long-term durability of wood products often provide little guidance on interpretation of test results. Decisions on acceptable performance for standardization and code compliance are based on the judgment of reviewers or committees. This decision-making process has potential pitfalls, especially when there is pressure to minimize the time needed for evaluation. This paper discusses some of the pitfalls encountered in interpretation of in-ground and above-ground durability test data and suggests areas where more prescriptive performance criteria may be warranted.

Keywords: Durability, performance criteria, evaluation methods, wood products

1. Introduction

The evolution in durable wood products continues to accelerate. Safety and environmental concerns with traditional and second generation wood preservatives have led to the evaluation of less toxic preservatives and alternatives to preservative treatment. In the United States the effects of withdrawal of chromated copper arsenate (CCA) from most lumber applications in 2004 continues to ripple through the industry. The last few years have seen the introduction and rapid acceptance of a micronized copper formulation of alkaline copper quat (ACQ) as well as the introduction and commercialization of two metal-free organic preservative systems. Numerous other types of preservative formulations are rumored to be on the near horizon. A barrier wrap system has gained acceptance for use in combination with lower preservative retentions,

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and there is increasing interest in the use of naturally durable tropical hardwoods. Non-preservative approaches to durability such as thermal treatments and modified wood have been commercialized in European countries, and their potential is being explored in the United States.

This trend of rapid changes in types of preservative treatments appears likely to continue. In the United States one of the drivers in this process has been the formation of the ICC-ES (International Code Council- Evaluation Service (ICC-ES) in 2003. The ICC-ES provides an additional route for proponents of potential new preservative treatments to demonstrate compliance with building codes. Prior to the formation of the ICC-ES, building code acceptance was typically achieved through standardization in the American Wood Protection Association (AWPA, formerly American Wood-Preservers' Association). Although most of the recent activity has targeted residential applications for treated wood, changes in preservative treatments for industrial applications are also a possibility. Creosote, pentachlorophenol and CCA are currently undergoing review by the U.S. EPA, with decisions on future allowable uses expected in 2008. In many European countries the movement away from traditional preservative treatments occurred earlier than in the United States, but change continues in these countries as well. Preservatives that were considered benign a decade ago face increasing scrutiny from regulators and the public.

The rapid evolution of durable wood products has further highlighted an old problem in wood preservation... how do we evaluate long term durability with short term tests? There is no shortage of test methods. Over the last century numerous laboratory and field test methods have been developed to evaluate durability, and many of these methods have gained broad acceptance in Europe, Australia, Asia and the United States. In the United States the AWPA has over 20 preservative evaluation standard methods, and other organizations, such as ASTM International, have applicable methods as well. The AWPA and ICC-ES both provide lists of tests that must be conducted before a durable product can expect to gain acceptance. The ICC-ES typically prescribes that AWPA test methods be used to evaluate a preservative. These methods detail the testing procedures, and in some cases suggest or prescribe the manner of presenting the results. However, the methods generally provide little guidance on how to interpret the results in terms of expected service life or in terms of "pass/fail" criteria. In other words, what is the significance of an average stake rating of 9.0 after 3 years exposure? Does this rating demonstrate efficacy of a preservative in ground-contact? A similar problem in data interpretation exists in European countries, where there is a need for a harmonized system for durability classification (Brischke and Rapp, 2007). Standards used in some countries do provide more guidance than those used in the United States, and some countries have attempted to address this concern by incorporating approval criteria into their testing protocols. For example, acceptance of a candidate preservative may be based on its equivalent performance to reference preservative once specimens treated with the reference preservative have degraded to below 70% mean soundness (AWPC, 1997).

In the United States the interpretation of test results has traditionally been handled through debates and votes within the committee structure of the AWPA. AWPA subcommittees are composed of representatives from industry, academia and government agencies who have some familiarity with conducting and interpreting durability evaluations. The durability results of test products are compared with those of established durable products and non-durable controls. Ultimately, however, the decision of acceptable performance and standardization remains semi-qualitative. This process has the advantage of flexibility; it allows subcommittee members to consider a wide range of factors that may affect interpretation of test results. However, it is also vulnerable to subjectivity, and potentially the tendency toward a lowering of the bar in judging acceptable performance. Although the process of considering data packets differs somewhat in the ICC-ES, the potential problem of subjective interpretation remains. In this paper we discuss some of the pitfalls encountered in interpretation of durability test data, and suggest areas where more prescriptive performance criteria may be warranted.

2. Ground Contact Durability Evaluations

Ground-contact field exposures have been used to evaluate durability for over a century, and stake and post tests continue to be the primary test method for products intended for use in ground contact. However, there are several factors that can interact to affect the results of these tests. Perhaps the most important of these factors are site conditions and duration of the test. It has long been recognized that deterioration is more rapid in warm, moist climates than in cool or dry climates. The AWPA standards recognize that climate affects the rate of deterioration, stating that while the minimum exposure time is 3 years in high decay hazard areas such as southern Mississippi, longer exposure times are required for lower decay hazard test sites such as Wisconsin. It is left up to the discretion of the subcommittee evaluating the proposal to determine whether the length of the exposure is adequate, but in the past 3 - 5 years of data have generally been considered to be sufficient. However, a comparison of matched sets of stakes (Figure 1), demonstrates that the results derived from northern climates are potentially misleading, even with longer exposures. In this case the test preservative had an average rating of 9 after 5 years of exposure in Wisconsin. Based on these data one might have the impression that the formulation is a promising candidate for protecting wood in ground contact applications. It is apparent from the Mississippi data, however, that this formulation will not adequately protect wood used in the southeastern U.S.

Similar challenges in interpreting data from different sites are encountered in European countries (Edlund et al, 2006; Brischke and Rapp, 2007). The performance of untreated controls does provide some indication of the severity of a test site, but controls may fail so rapidly that the data is difficult to use in developing adjustment factors. It has been proposed that the differences in sites be can be partially accounted for by creating adjustment factors based on the relative performance of reference materials at various sites (Brischke and Rapp, 2007). While this approach would remove some of the subjectivity in determining the required length of exposure, it is not a perfect solution because the effect of test site on preservative performance is a function of the formulation (or type of product) being evaluated. Thus, we cannot always assume that exposure for a certain number of years in a moderately severe site is equivalent to exposure for a certain number of years in a more severe location. Perhaps the most practical solution is to require data from at least one test site that has demonstrated a severe deterioration hazard.

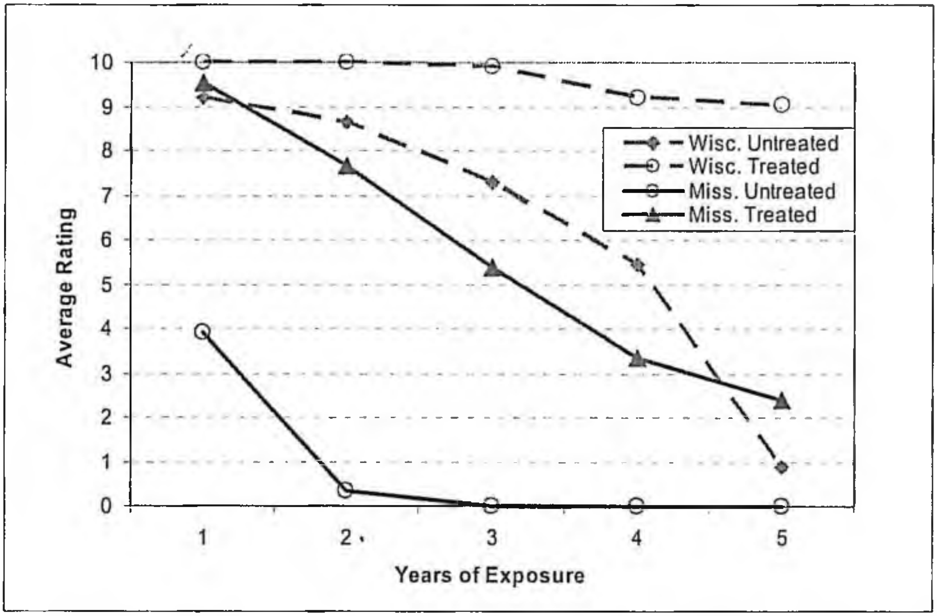

Figure 1. Example of difference in ratings obtained for stakes exposed in Wisconsin (moderate hazard) and Mississippi (severe hazard).

Length of exposure is also a concern even within high decay hazard areas. As mentioned above, a minimum of three years is specified in AWPA guidelines for preservative evaluation. However, it is far from clear that three years is sufficient. For example, consider the ratings of stakes in one of the USDA, Forest Products Laboratory's plots in southern Mississippi. This plot contains over 100 treatment groups (preservative/wood species/retention combinations), each of which was replicated with 20 stakes (19 by 19 by 457 mm). In Figure 2 we graphically compare how well the average stake ratings at three years correspond to their ratings after 11 years of exposure (the most recent rating of this plot). Treatment groups with an average rating of less than 9.4 after three years all performed poorly, with average ratings falling below 3 after 11 years. Treatment groups with an average rating of 10.0 (all 20 stakes rated as perfect) after three years faired better, but only half of these groups appeared to perform as well as the reference preservative (ground-contact retention of chromated copper arsenate, CCA Type C) after 11 years. And, 4 of the treatment groups with an average rating of 10.0 after 3 years had declined to an average rating of 7 or below after 11 years. Thus, perfect ratings or equivalent performance to CCA after three years does not provide a high degree of confidence that a test system will be performing similarly to the reference preservative over the long term. Increasing the duration of the test to 5 years improved the prediction of performance at 11 years. Eleven of the 18 groups performing as well as CCA after 5 years (average rating of 9.85 or above) continued to perform at least as well as CCA after 11 years. However, ratings of 2 of these groups did drop substantially between 5 and 11 years. None of the 15 treatment groups with average ratings between 9.0 and 9.8 after 5 years were performing as well as CCA after 11 years, and average ratings of 6 of these groups dropped to 7 or below. This indicates that even small differences in average ratings in the 9 – 10 range are important in predicting future performance. It is worthwhile noting that all of the systems evaluated in this plot are considered to be relatively resistant to leaching. These data indicate that when evaluating preservatives intended for use in ground contact in high hazard areas, a minimum of at least 5 years of exposure data is needed, and that the average rating of the test preservative should be at least as high as that of the reference preservative. Even slight evidence of vulnerability after 5 years appears to be a strong indicator of poor future performance. Studies are needed to explore these temporal relationships in greater detail while accounting for the possible underlying dependencies.

The European Standard EN 252 for ground contact exposure does require a minimum of 5 years of testing before results can be interpreted (CEN, 1998). However, similar concerns have been expressed about the use of 5 year data from Nordic test plots to predict long term performance (Edlund et al., 2006). Edlund et al compared the average ratings of over 700 treatment groups (approximately 10,000 total stakes) at 5 and 10 years to their median life and concluded that even treatment groups with no signs of decay after 5 or even 10 years may have a relatively short median life (Edlund et al., 2006). One treatment group with no evidence of decay after 10 years had a median life of only 14 years.

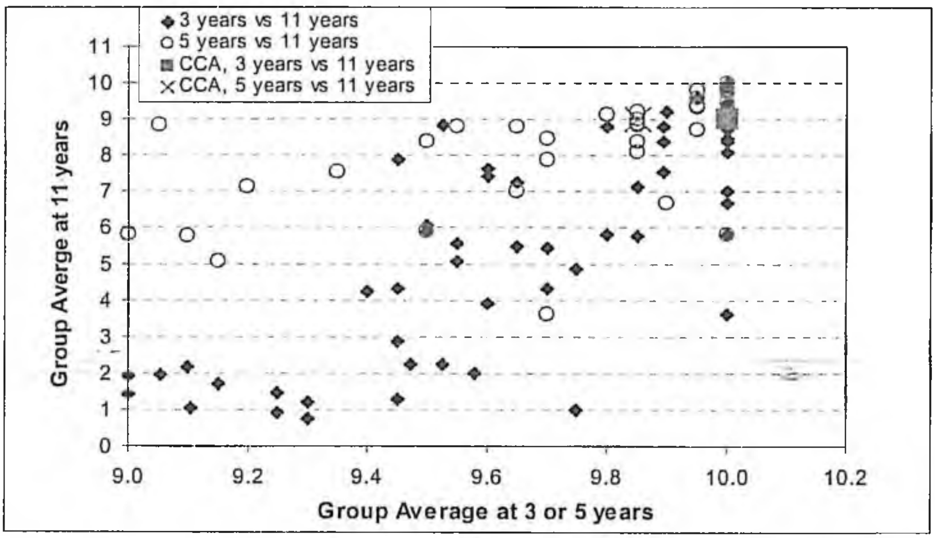

Figure 2. Comparison of average ratings at 3 years or 5 years to average ratings after 11 years. Each point represents the average of 20 replicates.

3. Above-Ground Durability Evaluations

Evaluation of preservatives intended for wood used above-ground has proven even more difficult than ground contact evaluations. Although it is recognized that the decay environment presented by stake tests is very severe for products intended for use above-ground, the selection of an appropriate above-ground test method has been problematic. The greatest source of difficulty appears to be the wide variations in severity of exposure for wood used above-ground. The severity of above ground exposure does vary with climate (Lebow and Highley, 2008; Rapp et al., 2006; Zahora, 2002), but it also varies greatly with construction practices and localized site conditions that influence moisture, temperature and UV exposure. In areas where organic debris can collect in connections, the above-ground decay hazard can be high (Figure 3).

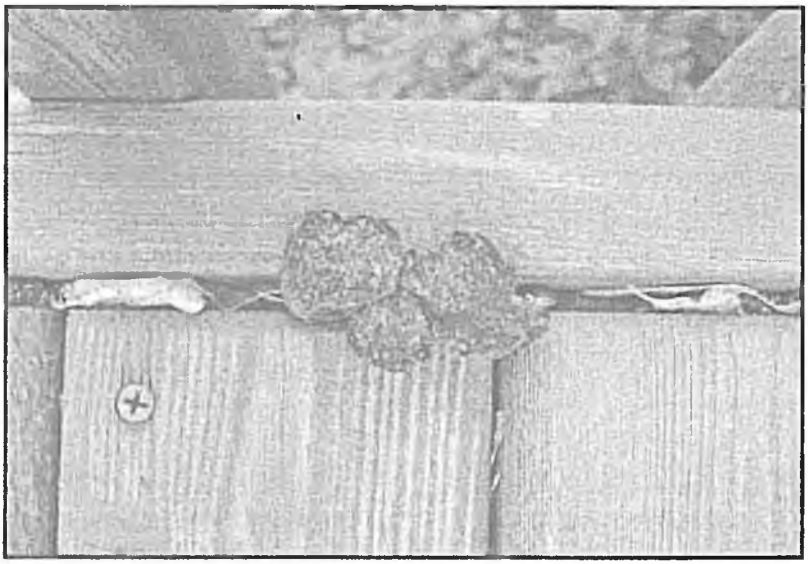

Figure 3. Accumulated organic debris helped to promote decay in the end-grain of this cedar decking.

A wide range of test methods has been used to evaluate above-ground decay (Blom and Bergstrom, 2006; Clausen et al., 2006; De Groot and Highley, 1995; Highley, 1995; Lindegaard and Morsing, 2003; Van Acker and Stevens, 2003; Zahora, 2002). Substantial research on above-ground evaluations continues to take place in Europe, where the transition to use of "above-ground only" preservatives has preceeded that in the United States. Despite extensive research however, it remains unclear how well above-ground tests characterize the hazard, or if they actually accelerate the rate of decay relative to in-service applications. Much of the difficulty is derived from creating test arrangements that simulate the moisture-trapping conditions present in actual structures. Most methods utilize some type of joint, connection or layering in an effort to trap moisture (Figure 4), but this effect can be undermined by the use of specimens with small dimensions. Although the smaller dimensions do allow more rapid detection of decay once it is present, smaller specimens dry more rapidly than dimension lumber. Smaller specimens also may be less susceptible to the formation of the checks that allow penetration and trapping of moisture in larger material (De Groot and Highley, 1995). Thus, although we associate the use of small specimens with accelerated testing for wood placed in ground contact, this assumption may be misleading for above-ground evaluations. Some studies suggest that common test arrangements may actually slow the time needed for decay to develop. In a comparison of tests units of untreated southern pine sapwood exposed above-ground in southern Mississippi, the most rapid visually evident failure (6 years) was achieved by simply using 102 mm thick planks (De Groot and Highley 1995; Esyln et al., 1985) (Figure 5). An earlier study reported that initial decay was not observed in untreated pine cross-brace units (20 x 75 x 15 mm) until after 6 years of exposure in southern Mississippi (Esyln et al., 1985). In contrast, the authors of this report often observe fruiting bodies of the brown rot fungus *Gloeophyllum sepiarium* after only three years of exposure of southern pine decking specimens (38 by 140 x 914 mm) in the lower decay hazard climate of southern Wisconsin. It is worth noting that visual evidence of decay is often a delayed indicator of fungal colonization. It is possible to culture the white-rot fungus *Irpex lacteus* from both lap joints and L-joints after as little as 4 months of exposure in Wisconsin. In addition to the effects of specimen dimensions, none of the commonly used test methods simulate the accumulation of decaying organic debris that often occurs in connections of treated wood used above-ground. Specimens are typically exposed in open areas to remove variability associated with natural shading, and when organic debris does accumulate it is removed during periodic inspections. The role of shading in promoting above-ground decay was reported by Augusta and Rapp (2003) and Rapp et al. (2006), who attributed the effect to the increased wood moisture content.

Above-ground evaluations are further complicated when the effects of wood species and composite products are considered. Although wood species do have some affect on ground-contact durability, the relative species effect becomes much greater in the slower deterioration that occurs above-ground. In evaluations of sapwood much of the species effects may be attributed to permeability, or resistance to moisture absorption. Several studies have reported substantial differences in wood moisture content for wood species exposed under identical test conditions, (Blom and Bergstrom, 2006; Lindegaard and Morsing, 2003; Miltz et al., 1998). Because moisture content is the primary limiting factor in above-ground decay, even small differences in moisture content can affect durability evaluations. Moisture absorption and retention also differ greatly for composite products. The quantity and properties of the adhesive, and the shape and orientation of the furnish greatly influence moisture absorption. In some cases initial moisture absorption is low, but increases over time as irreversible swelling occurs (Laks and Larkin, 2007). The wood fibers within wood-plastic composites products are particularly slow to acquire moisture, but fibers near the surface eventually do gain and maintain sufficient moisture to sustain decay (Clemons and Ibach, 2004; Wang and Morrell, 2004). Specialized test methods may be required to evaluate durability in these products.

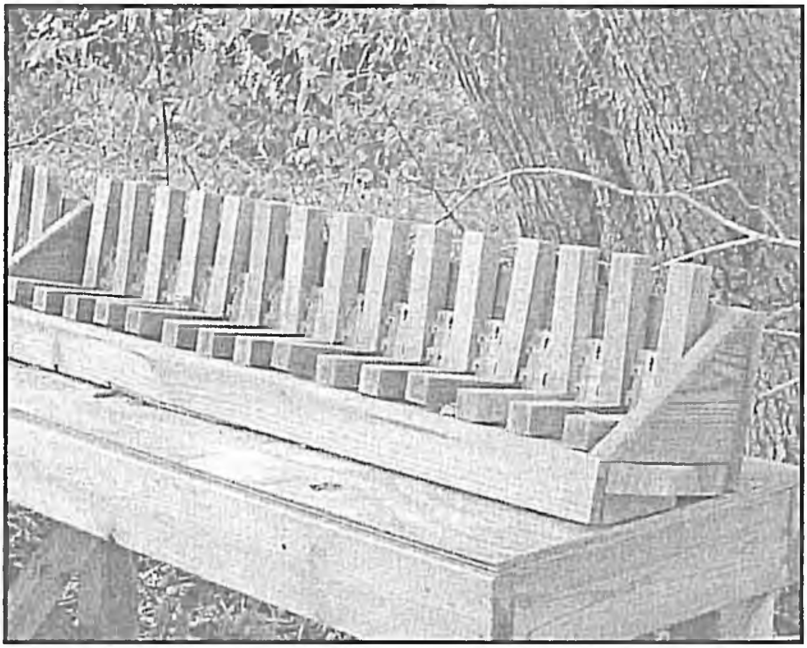

Figure 4. L-joint specimens are configured to trap moisture with the intent of accelerating fungal colonization.

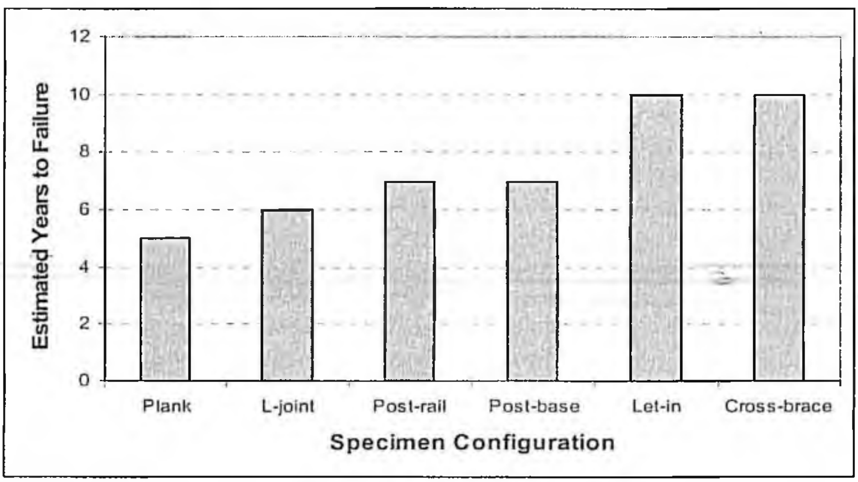

Figure 5. Estimated years to failure for various specimen configurations of untreated southern pine sapwood exposed above ground in a high decay hazard climate.

In the United States the AWPA currently lists three standard field test methods for evaluating above-ground decay: the L-joint method (Standard E9), lap-joint method (Standard E16) and the ground-proximity method (Standard E18). The lap joint method attempts to address the shortcomings of small specimen dimensions and debris accumulation by providing a larger joint area that is conducive to moisture development. The ground-proximity test is a newer method that is intended to provide a more severe exposure because the specimens are placed directly on cinder blocks and covered with shade cloth (Zahora, 2002). However, it uses small (19 by 50 by 125 mm) specimens without any overlap or joint areas, and its relative severity appears to vary with location. A fourth method, utilizing decking specimens, is in the final stages of the standardization process. Under current AWPA guidelines any of these standardized methods can be used to evaluate above-ground durability for any intended above-ground use.

The European standards also incorporate two above-ground testing methods. Standard ENV 12037 is a lap-joint method for general evaluation of wood to be used above-ground, while Standard EN330 is an L-joint method primarily intended for evaluation of wood that will be coated in service (CEN, 1993; CEN, 1996). Standard ENV 12037 does provide guidance on test duration, requiring that the test be continued until the untreated controls reach a mean rating of 3 (severe decay). Standard EN 330 recommends that the test be continued for a minimum of 5 years, and preferably until failure.

Both the United States and European methods do point out that meaningful results are not obtained until the untreated specimens reach a certain level of deterioration, but AWPA guidelines for preservative evaluation also state that a minimum of only three years of data may be needed in high hazard climates. This relatively short test duration may be based on the optimistic assumption that the above-ground test arrangements provide for accelerated testing. The standard methods do not provide criteria for ratings that would be considered acceptable or "passing" for the preservative-treated specimens, and given our uncertainty about the relationship between the results of these tests and in-service performance such criteria may be difficult to develop. It is also worth noting that although we may associate above-ground treatments with decking, the same use category also applies to structurally critical support members used above-ground. Given the ramifications of failure in some of these members (e.g., second story balcony supports) some consideration should be given to providing more conservative durability estimates. There may be value in returning to the use of stake tests to provide truly accelerated evaluations for preservatives intended for use above-ground.

4. Reporting Average Ratings

It has become common practice to report only average ratings in preservative evaluation data packets submitted to AWPA, and we have routinely referred to average ratings in this paper as well. While averages are perhaps the single most descriptive statistic, they do not always accurately characterize the performance of a preservative system (De Groot and Evans, 1998, 1999; Link and De Groot, 1989). Variability in performance and the occurrence of early failures can provide important information in evaluating a preservative. Figure 6 provides an example of how average ratings may not fully capture the performance of copper based preservatives. In this case 20 replicates were used, and the treatment group had respectable average ratings of 8.9 after four years and 7.7 after 5 years of exposure in a severe decay environment. However, within 3 years 2 of the stakes had failed completely, and after 5 years a total of 4 of the 20 stakes had failed. All of the remaining stakes had ratings of either 9 or 10, with 10 remaining the most common (mode) rating. This pattern of high ratings for most stakes and complete failures of others is frequently observed in tests of copper-based preservatives in plots where copper tolerant fungi are present. Likewise, termite distribution is inherently non-uniform within a test plot and this may also affect the performance of individual stakes. In other situations, such as with some naturally durable species, there may be a wide distribution of durability ratings between specimens that is not adequately characterized by simply presenting the average rating. Link and De Groot (1989) discuss the problem of relying too heavily on average ratings, and suggest the use of box plots to characterize the "time to failure" for stakes within each treatment group. Prior to 2003, the AWPA standards did include a method for more detailed data analysis and presentation. However, this "Standard Procedure for the Calculation of the Performance Index of Preservatives in Stakes and Posts" was mathematically complex and the standard was eventually removed for lack of use. For key durability tests it may be worthwhile to again provide additional guidance on the type of data presented in summarizing the performance of a candidate preservative system. This guidance could be as simple as prescribing the type of data presented (i.e. box plots or number of stakes in each rating category) or a more thorough statistical analysis.

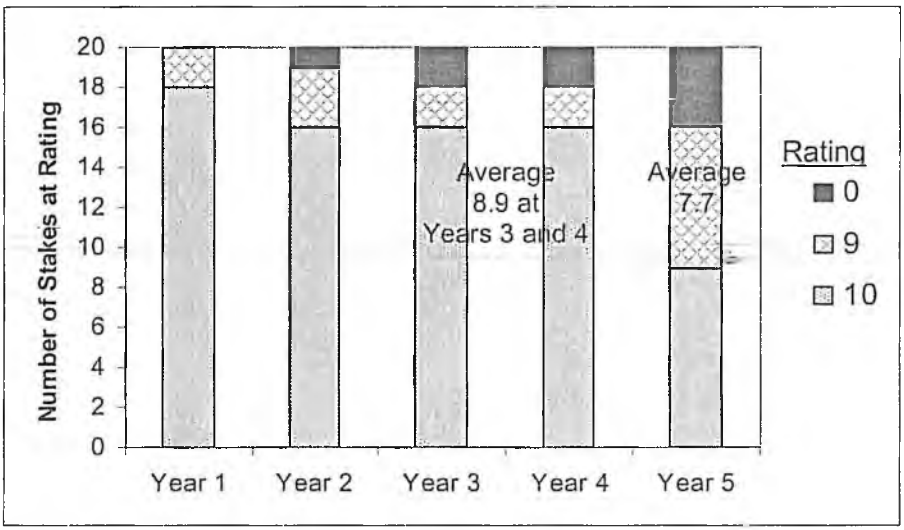

Figure 6. Example of average ratings masking the occurrence of early failures.

5. Conclusions and Recommendations

The increasing pressure to rapidly evaluate and commercialize durable wood products is challenging our ability to interpret the results of short-term durability tests. The current process of subjectively interpreting data packets is vulnerable to the pressure for rapid commercialization, and there is potential for a loss of conservatism in our performance criteria. In the United States data packets may be reviewed by organizations whose members are not familiar with the intricacies of wood product durability evaluations.

For evaluation of products intended for use in contact with the ground, it appears that even extended durability evaluations conducted in less severe (northern) climates may not be adequate for estimation of durability in more severe climates. A practical solution would be to require data from at least one test site that has demonstrated a severe deterioration hazard. Even in severe decay hazard climates, excellent performance of stakes after only three years is not a reliable indicator of long term durability. Basing test duration or performance criteria on the durability of untreated controls also does not appear to be sufficient for ground contact evaluations. The approach used in Australia, where test duration is based on the performance of low concentrations of an established reference preservative, does appear to have some merit.

Our current methods of assessing above-ground durability may not accelerate decay in comparison to some conditions encountered for durable wood products in service, suggesting that much longer evaluation periods or more severe tests should be considered. Alternatively, above-ground uses could be further divided, with more stringent test methods utilized for products intended as above-ground structural supports. Ground-contact testing of products used in structurally critical above-ground members may be necessary until appropriate above-ground test methods are developed.

Interpretation of test data also remains problematic. A return to more prescriptive data presentation may be warranted, as average ratings do not always adequately characterize the performance of a durable product. In addition, methods should provide more specific guidance on the distribution of ratings that is considered to represent adequate performance.

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