A Comparison of the Durability of Two Stake Sizes in Southern Mississippi

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ABSTRACT

The small stakes used in preservative evaluation are thought to accelerate deterioration relative to larger in-service members, but the extent of the acceleration is poorly understood. This paper compares the durability of the commonly used 19- by 19-mm stakes to larger 38- by 89-mm (nominal 2 by 4) stakes that more closely resemble commodity-size material. The years to reach average ratings corresponding to loss of 10% of the cross section or complete failure were compared for 53 sets of matched 19- by 19-mm and 38- by 89-mm stakes exposed in plots near Saucier, Mississippi. The larger stakes required an average of 2.1 times longer to reach an average rating corresponding to loss of 10% of the cross section, but this ratio ranged from as low as 1.0 to as high as 8.0. It took an average of 2.2 times longer for the larger stakes to fail, with maximum and minimum ratios of 3.5 and 1.4, respectively. The efficacy of the preservative system appeared to have little consistent effect on relative longevity of the two stakes sizes. Linear regression of average years to loss of 10% of the cross section or failure for the two stake sizes yielded R^2 values of 0.60 and 0.69, respectively. The data indicate substantial uncertainty in using the durability of 19- by 19-mm stakes to predict the durability of 38- by 89-mm stakes, and by extension, the durability of in-service members.

Keywords: Stake size, durability, ratings, commodity-size, prediction

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INTRODUCTION

Stake tests are one of the most commonly used methods for evaluating the efficacy of new preservative formulations. In the United States, most stake tests are conducted with 19- by 19-mm (0.75 in- by 0.75 in-) stakes, although some are conducted with the thinner Fahlstrom [a small stake test procedure for accelerated evaluation of wood preservatives] stakes. Stakes with these relatively small dimensions are used because they are thought to have accelerated deterioration relative to larger 38- by 89-mm (nominal 2 by 4) stakes or posts, and therefore shorten the time needed to evaluate new formulations. Small stakes do generally fail more rapidly than 38- by 89-mm stakes and so provide accelerated information on the relative efficacy of a test formulation in comparison to a reference preservative. However, it is unclear how their ratings or durability correspond to the service life of larger commercial members. Researchers are increasingly interested in improving our understanding of how years in test for these small stakes might relate to years in service for larger, commodity-size material. We assume that the larger commodity-size material will be substantially more durable than the small stakes, but this relationship has not been determined. One approach to understanding the relationship between the durability of 19- by 19-mm stakes and commodity-size material is to compare the durability ratings for 19- by 19-mm and 38- by 89-mm stakes.

It is important to remember that, even for the larger stakes, stake life is not the same as service life. Test stakes are evaluated using a visual rating system corresponding to an estimated loss of cross section (Table 1).

Table 1—Typical rating scheme for evaluation of stakes

Rating	Description of condition
10	No evidence of attack
9.5[a]	Trace termite attack or softening or discoloration associated with suspected fungal activity
9	Slight attack, up to 3% of cross-sectional area
8	Moderate attack, up to 10% of cross-sectional area
7	Moderate to severe attack, up to 30% of cross-sectional area
6	Severe attack, up to 50% of cross-sectional area
4	Very severe attack, up to 75% of cross-sectional area
0	Failure. Can be broken easily by hand or the evaluation probe can penetrate through the stake.

[a]This rating was only recently added to the rating scheme and was not used for any of the stakes evaluated in this paper.

The life of stakes has typically been reported as either years to failure or years to some intermediate rating, such as "8" or "7" (Link and DeGroot 1989; Colley 1970; Crawford et al. 2002; Hartford 1972). It is unclear how these ratings correspond to the life of an in-service structural member, although it seems unlikely that years to failure of research stakes is an ideal measure of service life for load-bearing members. Even the extent of degradation corresponding to "8" or "7" in a structural member is likely to be cause for substantial concern if observed by an engineer, inspection service, or homeowner. Given that decay can cause substantial reductions in mechanical properties at low weight losses (Clausen and Kartal 2003; Wilcox 1978; Winandy and Morrell 1993), such concern is probably warranted. It is also worth noting that in most cases, a group of stakes with an average rating of "7" has one or more stakes with a lower rating. The smaller 19- by 19-mm stakes less frequently have ratings of "7" and rarely have ratings of "6" or "4" because they become fragile at the lower ratings. Instead, they tend to drop from ratings of 9, 8, or 7 directly to 0. Because of this failure pattern, an average rating of "7" for a treatment group of 19- by 19-mm stakes usually indicates that two or more stakes have failed. For in-service members, such as utility poles, early failure of even 10% of the population would not be considered acceptable.

Comparisons of the durability of 19- by 19-mm and 38- by 89-mm stakes are difficult because of the lengthy testing period required. Fortunately, researchers at both Mississippi State University (MSU) and the U.S. Forest Service, Forest Products Laboratory (FPL) have previously installed similarly treated 38- by 89- and 19- by 19-mm stakes at test sites in Mississippi (Crawford et al. 2000; Schultz and Nicholas, in press). Schultz and Nicholas (in press) recently reported on a comparison of 19- by 19-mm and 38- by 89-mm stakes treated with copper systems and exposed at test sites near Saucier and Dorman, Mississippi. They found little relation ($R^2 < 0.5$) between the ratings of 19- by 19-mm stakes exposed for 39 months and 38- by 89-mm stakes exposed for 210 months at the Dorman site. Schultz and Nicholas also compared the ratings of the 19- by 19-mm stakes exposed for 17 years at Saucier to ratings of 38- by 89-mm stakes exposed for 17 years at the Dorman site. They reported a moderate relationship ($R^2 = 0.68$) with the poorest formulation, but a weaker relationship ($R^2 < 0.5$) for the two other formulations (Schultz and Nicholas, in press). As the authors note, these differences reflect the effects of both stake size and site conditions.

The relatively poor relationship between the ratings for the two stake sizes noted by Schultz and Nicholas (in press) is intriguing and has serious implications for our ability to use ratings from 19- by 19-mm stakes to predict durability of larger members. In this paper, we further explore this topic by comparing the durability of 19- by 19-mm and 38- by 89-mm stakes exposed at the FPL's test site near Saucier, Mississippi.

MATERIALS AND METHODS

The FPL has been conducting stake durability evaluations at Harrison Experimental Forest (HEF) since the 1930s. Over the years, FPL scientists have placed combinations of treatment groups into individual plots. In some cases, FPL scientists installed both 19- by 19-mm and 38- by 89-mm stakes into these plots. We reviewed all plots at HEF to determine which plots had matched sets of 19- by 19-mm and 38- by 89-mm stakes of equivalent or similar retentions installed in the same year. This review located 64 matched sets. The data for these treatment groups were only used if the average ratings of both the 19- by 19-mm and the 38- by 89-mm stakes had declined below "8," and a total of 53 treatment groups meet this criterion (Table 2). Of these, 17 treatment groups had also reached the point of complete failure of all stakes of both sizes (average rating of "0"). Each treatment group initially contained 10 replicate stakes. For each treatment group and stake size, the number of years for the average rating to drop below "8" and to reach "0" (if available) was calculated. The rating of "8" was selected as the earliest measure of service life because it represents a point where deterioration becomes obvious and likely to be a cause for concern and replacement in an in-service structure. The rating of "8" also translates directly from rating of "3" (partial or limited decay) that was used for some of the ratings prior to 1991. The rating of "0" (all stakes failed) was selected as the least conservative estimate of service life. The data for years to average rating of zero is potentially biased because less than 33% of the treatment groups evaluated have reached this point, and these groups may over-represent the less durable treatments. It is also worth noting that each plot at HEF represents a stand-alone study, and that there was not a systematic effort to establish plots with both stake sizes. Thus, plots with both stake sizes are not necessarily representative of all plots or treatments evaluated at HEF.

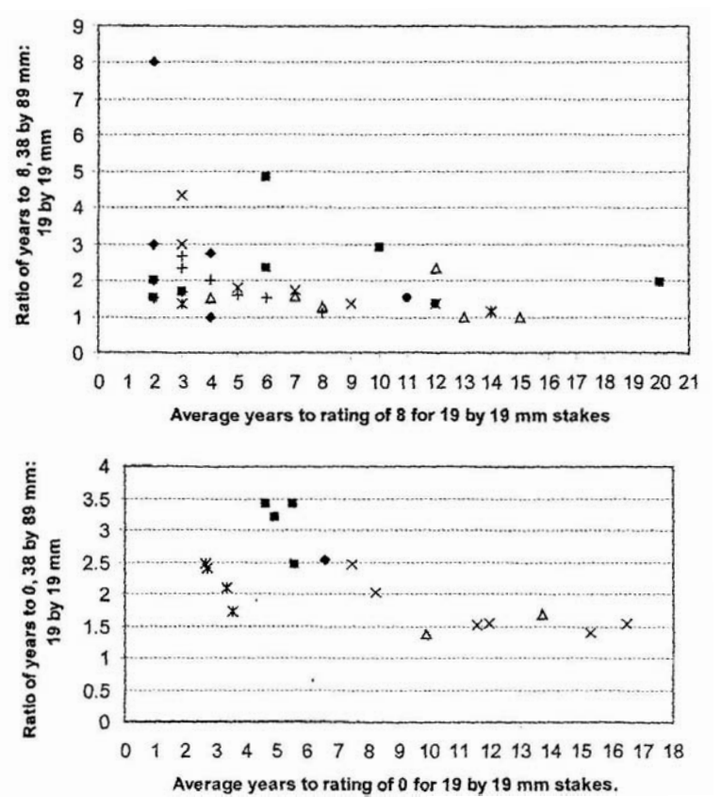

Figure 1. Ratios of average years to rating of "8" or "0" for the two stake sizes. Marker style shows stakes from the same plot.

RESULTS AND DISCUSSION

The larger stakes required an average of 2.1 times longer to reach an average rating of "8," but this ratio ranged from as low as 1.00 to as high as 8.00 (Figure 1). It took an average of 2.2 times longer for the larger stakes to reach an average rating of zero, with maximum and minimum ratios of 3.46 and 1.36, respectively (Figure 1). The average ratio for years to "8" and years to "0" for the two stake sizes is surprisingly similar given that the larger stakes might be expected to survive more years with lower ratings (i.e., ratings of 7, 6, or 4) than the more fragile 19- by 19-mm stakes.

An intuitive assumption is that the efficacy of a preservative system will affect the relationship between the durability of the two stake sizes. When the data are combined, there does appear to be a slight tendency for the ratio of years to rating of "8" for the two stake sizes to decline as the durability of the 19- by 19-mm stakes increases (Figure 1). However, this trend isn't as apparent within the individual plots. The relationship between longevity and the ratio of the two stake sizes is even less well-defined for years to an average rating of "0." In general, the data indicate that efficacy of the preservative system has little consistent effect on relative longevity of the two stake sizes. However, the years to zero data may be biased because they reflect only the least durable third of the treatment groups evaluated.

It is also logical to expect that the relative durability of larger stakes might be greater for formulations with greater preservative mobility (or leaching) because the larger stakes would have a greater internal reservoir of preservative to replace that lost from the surface. This expectation appears to be fulfilled in some cases. For example, the coal tar creosote treatment and the heavy petroleum oil treatment have relatively great (2.33 and 2.75, respectively) large stake:small stake years to rating of "8" ratios. Similarly, CCA is quite leach resistant and has a relatively small (1.57) large stake:small stake years to "8" ratio. However, groups treated with pentachlorophenol in P9 Type A solvent, which is thought to have mobility, has several of the lower large stake:small stake ratios for years to "8" rating.

It is also difficult to draw strong conclusions about how the type of preservative formulation (i.e., waterborne or oil-type) might affect the relative performance of the two stake sizes. This is largely because many of the formulations do not fall clearly into the classic categories of "fixed" waterborne or oil-type preservatives. There are also conflicts between similar formulations. For example, in one plot the ratio of years to rating of ''8" for pentachlorophenol in AWPA P9 Type A oil was only 1.1, whereas in another plot the ratio was 4.8. Similarly, within the 6 FCAP formulations/retentions evaluated, the ratio of years to rating of "8" varies from 1.3 to 4.3.

Although the use of multiplicative factors (ratios) to compare durability in this study is convenient, it should be recognized that biodeterioration is a complex process that is unlikely to be explained by a simple multiplicative factor. Evidence of the difficulty in assuming a constant factor can be seen in Figure 1, where the ratios appear to decline as the durability of the stakes increase. The use of a multiplicative constant could also suggest that the durability relationship between stake sizes is simply a function of their surface area to volume ratio. Interestingly, the 19- by 19-mm stakes have a surface area to volume ratio 2.7 times greater than that of the 38- by 89-mm stakes, which is reasonably close to the inverse of their ratios of years to rating of "8" (2.2) and years to failure (2.1). However, as noted in Figure 1, the ratios for individual treatment groups vary greatly, possibly in part because neither decay nor termite attack is necessarily a surface phenomena. The surface area to volume ratio of stakes may be a more reliable predictor of durability for degradation that moves from the surface inward, such as soft-rot attack.

It is apparent that the relationship between the durability of the 19- by 19-mm versus the 38- by 89-mm stakes vanes substantially. This variability presents challenges in using the performance of 19- by 19-mm stakes to predict the durability of 38- by 89-mm stakes or larger members in-service. A linear regression of the years to rating of "8" for the 19- by 19-mm stakes versus the 38- by 89-mm stakes yielded an R^2 of 0.60, with a slope of 1.39 and a y-intercept of 2.51 (Figure 2).

This relationship would predict. for example, that if the 19- by 19-mm stakes reach a rating of "8" in an average of 10 years, then the larger 38- by 89-mm stakes would reach a rating of ''8" in an average of 16.4 years. However, as indicated by the relatively low R^2 value, there is substantial variability in this estimate, and the lower and upper 95% confidence intervals for the 16.4-year estimate are 6.6 and 26.6 years, respectively (Figure 2). A linear regression of average years to "0" rating for the two stake sizes yields a slightly greater R^2 value (0.69) (Figure 3), but still indicates substantial uncertainty in predicting the performance of the larger stakes from the 19- by 19-mm stakes.

Table 2 — Treatments compared and average years to rating of "8" or "0" for each stake size

	Retention (kg/m³) for each stake size (mm)		Years to average rating of "8" or "0" for each stake size (mm)			
			Years to "8"		Years to "0"	
Preservative formulation	38 by 89	19 by 19	38 by 89	19 by 19	38 by 89	19 by 19
Chromated copper arsenate, Type C	2.24	2.24	16	12	-	-
	2.40	2.24	13	11	-	-
	4.16	4.32	24	11	-	-
Chromated zinc chloride	11.36	11.68	11	7	22.9	13.7
Coal-tar creosote	163.20	186.56	28	12	-	-
Copper-8-quinolinolate (in water)	0.19	0.20	4	3	-	-
FCAP Type A	5.60	5.76	9	3	18.3	7.4
	8.00	8.16	12	9	18.5	11.9
	12.00	12.32	16	12	25.1	16.5
FCAP Type A Modified	5.60	5.92	9	5	16.7	8.3
	8.00	8.32	12	7	17.5	11.6
	12.16	12.80	13	3	21.4	15.3
KP (copper oxide and chlorophenol)	1.44	1.44	6	4	13.5	9.9
	3.04	2.88	10	8	-	16.4
	4.32	4.48	15	15	-	-
	5.92	5.92	13	13	-	25.6
Pentachlorophenol (PCP) in P-9 Type A solvent	7.68	7.52	16	14	-	-
PCP 4.2% in AWPA P-9 Type A solvent	4.64	3.84	29	6	-	-
	10.72	11.20	39	20	-	-
PCP 4% + paraffin 2% + Pentalyn-H	2.24	2.24	4	2	13.7	5.6
	2.88	2.56	4	2	15.9	4.9
PCP 5% + paraffin 2% + Pentalyn-H	6.08	5.12	14	6	-	-
	10.72	11.52	29	10	-	-
PCP in liquefied petroleum gas (LPG)	2.24	2.40	3	2	18.9	5.5
	3.04	3.04	4	2	15.9	4.6
	5.44	4.96	5	3	-	-
	9.28	7.68	5	3	-	-
PCP in LPG with isopropyl ether co-solvent	5.44	5.44	4	4	-	-
	6.24	6.40	4	2	-	-
	7.84	6.40	6	2	-	-
	10.40	9.44	16	2	-	-
PCP, ammonium	2.56	2.56	4	2	6.6	2.7
	3.20	3.52	3	2	6.1	3.5
	4.32	4.48	6	2	-	4.3
	6.08	6.72	5	3	-	-
	8.80	10.08	8	4	-	-
	12.32	14.24	8	5	-	-
PCP, emulsified	2.24	2.24	4	2	7.0	3.4
	3.20	3.36	6	2	-	-
	4.48	4.48	8	3	-	6.6
	6.40	6.40	8	4	-	-
	8.96	8.96	8	5	-	-
	12.96	12.96	9	8	-	-
PCP in P-9 Type A oil & toluene	2.24	2.56	8	5	-	-
	3.20	3.20	8	5	-	-
	4.48	4.32	9	6	-	-
PCP-creosote emulsion with 3% ammonia	2.24	2.24	4	2	6.5	2.7
	3.20	3.36	4	2	-	3.5
	4.48	4.80	7	3	-	5.1
	6.40	7.36	8	3	-	-
	8.80	9.28	8	4	-	-
	13.60	13.92	8	5	-	-
Petroleum oil, heavy	128.00	132.48	11	4	16.7	66

The relatively weak stake size relationships found in this paper are similar to those noted by Schultz and Nicholas (in press), confirming substantial uncertainty in using the ratings of 19- by 19-mm stakes to predict the performance of 38- by 89-mm stakes. It is worth noting that this study only evaluated data from matched sets of stakes placed within small plots. It is reasonable that the correlation would be even weaker when comparing the two stake sizes exposed at different locations, as was noted by Schultz and Nicholas (in press) in their earlier report. Unfortunately, this does not bode well for using ratings of 19- by 19-mm stakes to estimate the service-life of larger in-service members used for construction in multiple locations. Such predictions may be possible, but the associated confidence intervals are broad.

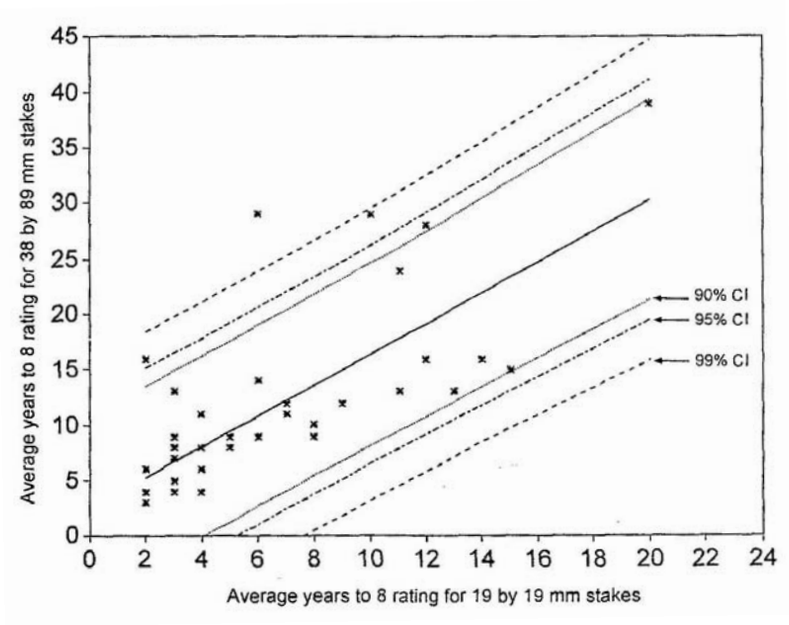

Figure 2. Regression of average years to "8" rating for the two stake sizes and confidence intervals for the regression line.

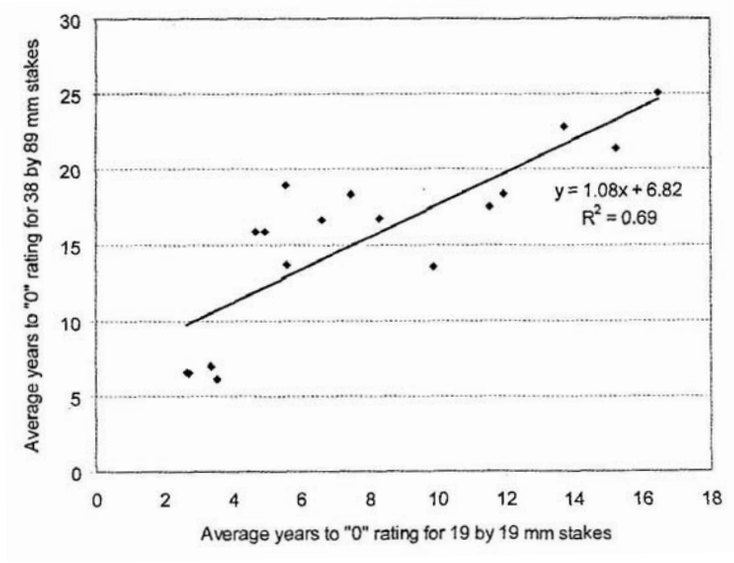

Figure 3. Regression of average years to "0" rating for the two stake sizes. Regression is potentially biased because most treatment groups have not yet reached a "0" rating.

CONCLUSIONS

Comparison of stake ratings in FPL's plots at Harrison Experimental Forest indicates substantial variability in the relationship between the durability of 19- by 19-mm and 38- by 89-mm stakes. The smaller stakes reached a rating of "8" or below an average of 2.1 times faster than the larger stakes, but this ratio ranged from as low as 1.0 to as high as 8.0. The ratio of average years to failure for the two stake sizes varied from 1.36 to 3.46, with an average of 2.2. A regression of years to average rating of "8" for the 19- by 19-mm versus the 38- by 89-mm stakes yielded an R^2 value of 0.60. These findings indicate that predictions of durability of the larger stakes from the smaller stakes would require wide confidence limits. The relationship between small stakes exposed in one location and larger stakes exposed in another location is likely to be even weaker. From the data evaluated in this study, it appears that the performance of 19- by 19-mm stakes provides only a general indication of the service-life of larger in-service members used in the same or other locations.

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