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THE INTERNATIONAL RESEARCH GROUP ON WOOD PRESERVATION
SECTION 2 TEST METHODOLOGY AND ASSESSMENT

NATURAL PROGRESSION OF DECAY IN UNRESTRAINED, SOUTHERN PINE SAPWOOD LUMBER EXPOSED ABOVE GROUND

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ABSTRACT

In this study, the natural progression of decay is being monitored in 2.4-m (8-ft) lengths of Southern Pine dimension lumber. The 2.4-m lengths are supported without restraint in a horizontal plane approximately 0.75 m above ground in a partially shaded field plot in southern Mississippi. The lumber is 100% sapwood. Prior to installation in the field, each piece was planed to exactly 38 by 89 mm (1.5 by 3.5 in.) when conditioned to 10% moisture content. Members were then sorted according to modulus of elasticity (MOE) into groups with equivalent mean and range. Sets were removed at intervals and the distribution of decay was nondestructively monitored by measuring speed-of-sound transmission through the width of each member. Analysis of the patterns of decay within the members permits design of optimum configuration of above-ground test units. Some key points of consideration were the large variation in amount of naturally occurring decay within a similar population of test units, density-dependent differences in rates of decay development, and overlapping members and end effects. Preliminary results indicate that decay does not become universally established simultaneously along the length of the members. Decay is detected first at the ends and with continued exposure, it progresses to locations more distant from the ends. Presumably, this reflects some contribution of wetting of the exposed end grain to early onset of wood decay.

INTRODUCTION

Within the continental United States, brown-rot decay fungi usually prevail in softwood construction used above ground. The principle objective of this study was to determine if nondestructive measurements will provide reliable estimates of residual strength in unrestrained, Southern Pine sapwood that is exposed above ground to naturally occurring decay fungi. This study is not yet complete. However, preliminary evaluations of exposed wood members have provided us with information on patterns of colonization by decay fungi determined by loss of weight in experimental members and speed of stress waves passing transversely through the nominal 50-mm (4-in.) thickness of the wood members. This report summarizes our preliminary observations.

LITERATURE REVIEW

Energy storage is manifested as the speed at which a wave travels in a material. In contrast, the rate at which a wave attenuates is an indication of energy dissipation. Jayne (1959) hypothesized that these properties are controlled by the same mechanisms that determine mechanical behavior of a material.

This hypothesis was verified by studies using clear wood and lumber products. Jayne (1959) was successful in demonstrating a relationship between energy storage and dissipation properties, measured by forced vibration techniques, and the static bending properties of small, clear wood specimens. Kaiserlik and Pellerin (1977) furthered the hypothesis by using stress wave techniques to evaluate the tensile strength of a small sample of clear lumber containing varying degrees of slope of grain. Pellerin and Morschauser (1974) verified the hypothesis on wood-based composites when they showed that wave speed could be used to predict the flexural properties of underpayment grade particleboard. Ross and Pellerin (1988) demonstrated that wave attenuation is

sensitive to bonding characteristics of wood-based composites and a, valuable nondestructive parameter that contributes significantly to the prediction of mechanical properties.

Stress wave speed was shown to be sensitive to the presence of decay in large Structural members (Hoyle and Rutherford 1987; Rutherford et al. 1987) . In general, as degradation progresses, wave speed decreases. This fact was well illustrated in the work by Pellerin et al. (1985) .

Based on the success of the previously noted research, we used stress wave technology to nondestructively monitor development of decay in exposed beams prior to destructive, physical characterization of residual strength properties of each member.

MATERIALS AND METHODS

All wood members used in this study were clear sapwood and cut from Southern Pine sapwood lumber, Class C or better. Lumber was obtained from a mill in Georgia, USA, and shipped to the USDA Forest Service, Forest Products laboratory (FPL), for processing. At FPL, the lumber was planed to uniform *cross* sectional dimensions of 38 by 89 mm (1.5 by 3.5 in.) and cut into 2.4-m (8-ft) lengths. This material was used as received from the mill with no additional sorting for density.

After planed to dimension, all materials were equilibrated to a constant weight in a conditioned room at which time wood achieved a moisture content of approximately 10%. Then, modulus of elasticity (MOE) was nondestructively determined for each member. After MOE values were determined, individual members *were* assigned to groups of 30, each within the experimental design according to a sorting that provided equivalent representation of MOE values in all groups. Within the experiment, groups of 30 replicates were used for each exposure interval.

All field exposures were conducted at the Harrison Experimental Forest in southern Mississippi, approximately 32.2 km (20 mi) from the Gulf of Mexico.

Members were packaged and shipped from FPL to the field site in lots of 30 replicates. Each lot of 30 was packaged separately and protected on the exterior with plywood so that ends and sides of the wood members would not be damaged in shipping or structurally damaged by mechanical lifts.

At the field site, members were exposed, within a forest clearing, in a horizontal position approximately 0.75 m above ground (Fig. 1). Members were rested on the 89-mm- (3.5-in.-) wide face and exposed with the long dimension in an east-west orientation. Members were partially shaded in early morning or late afternoon. To achieve a uniform distribution of microclimatic exposure with time, members were randomly located on racks within the east half *of* the opening.

Members were exposed to the elements up to 45 months (Table 1) . At the conclusion of each exposure interval, one lot of 30 replicate members was

removed from the field site and shipped back to FPL. At FPL, members were reequilibrated to a constant weight in a controlled environment until the wood reached a moisture content of 10%. The members were weighed again to determine weight loss as a result of decay.

Table 1. Field exposure of 2.4-m sapwood members.

Length of exposure[a] (month)	Number of members	Date of removal
0	30	----
4	30	August 1990
9	30	January 1991
14	30	June 1991
21	30	January 1992
26	30	June 1992
33	30	January 1993
45	30	January 1994

[a]Members were placed in the field March 27-28, 1990. Additional members remained in exposure.

Results from weight loss determinations are displayed using box plots (Velleman 1989). As illustrated in Figure 2, box plots show (1) the median (horizontal line with an asterisk on each side), (2) the mean (plus sign), (3) the middle 50% of data from the 25th to 75th percentiles (lower and upper boundaries of the box), (4) the lowest and highest values within a specific distance of the 25th and 75th percentiles (solid line, often called a whisker, extending from the box to a point where the maximum distance < l.5 times the distance from the 25th to 75th percentiles), and (5) the outlying data (asterisk), which were values more than 1.5 times but less that 3.0 times the box width. In addition to this descriptive information, a shaded region for each plot shows the result of testing if two plots have the same median value. The shaded regions enable comparison of medians at a 5% level of significance with a modified 95% confidence interval for the median. If the shaded regions do not overlap, the corresponding medians are significantly different at the 5% level. Box plots can also be used to assess the possible normality of the data set by looking for the symmetry and equality of mean and median that characterize a normal distribution.

Measurements of speed-of-sound transmission in the transverse direction were also performed on the reequilibrated members to monitor decay. The test setup used two 84-kHz rolling transducers coupled to an ultrasonic transmitter and receiving unit (Fig. 3) . Sound transmission times were displayed by the unit and recorded on a personal computer. With each member, transmission times were measured at 76.2-mm (3-in.) increments from each end for a distance of

304.8 mm (12 in.) from each end and at intervals of 152.4 (6 in.) along the length of the internal 1.8-m (6-ft) midsection (Fig. 4) .

Stress wave transmission times at each measurement location along the length of the member were plotted for each member. This provided us with a graph of the linear distribution of decay in each member. Average values for each location in each exposure group are presented in this paper. The distribution of average stress wave times for each member within the respective group at each interval of exposure was also plotted to gain another estimate of the variability within the exposed population.

RESULTS

Weight Loss Determinations

The range in percentage weight losses within each group increased with time of exposure (Fig. 5) . To determine whether rate at which weight loss occurred was influenced by the original weight (density) of the member, we compared, within each group at each exposure interval, the percentage weight loss that occurred in the original heaviest three members with the percentage weight loss that occurred in the original lightest three members in the respective groups (Fig. 6). No major difference in trends was apparent, but the variation within the respective small sets was often greater for the heaviest members. When the three highest percentages of weight loss were plotted at each observation, the trend in weight loss was consistently upward (Fig. 7) . However, within each group, some members showed relatively little weight loss (Fig. 7).

Overall, weight loss progressed slower than we anticipated at the outset of the experiment. Sporocarps of *Gloeophyllum saepiarium* and *Schizophyllum communae* were first observed at 14 months of exposure, at which time the median percentage weight loss was significantly greater than was observed at 4 and 9 months of exposure (Fig. 7) . When we made our last inspection in January 1995, decay had progressed in at least one member to the extent that it was no longer able to support its own weight. Weight loss has not yet been determined for those specimens. It will be interesting to determine how the weight loss distribution changed during the last year of exposure.

Stress Wave Measurements

Traces of transverse sound wave transit time obtained from each 2.4-m member prior to exposure showed little or no variation in sound transmission times along the length of the specimens. The observed times were similar to those previously reported for clear wood (Rutherford 1987; Volney 1992; Hoyle and Pellerin 1978; Aggour and Ragab 1982).

When the distribution of average sound transmission times for individual members within each group were inspected, the variation within data sets for each exposure interval again increased with time in exposure (Fig. 8) . Trends in average sound transmission time for each exposure group (Fig. 9) and each position within each group (Fig. 10) indicated that substantive increments in group sound transmission time (decreases in speed) did not occur prior to 21 months of exposure. Beginning at 21 months, elevated sound transmission times

occurred along the length of specimens, with the longest times near the ends (Fig. 10).

Average sound transmission times at each position within each exposure show that an increase in transmission time was observed at the ends of the members before it was observed within the members (Fig. 10) . With continued exposure, sound transmission times increased substantially at the ends and increased progressively at locations more distant from the ends.

We did not notice any marked development of decay, as evidenced by elevated sound transmission times, that seemed uniquely associated with the position at which the members rested upon the horizontal supports.

DISCUSSION

Elevated sound transmission times, that is, a decrease in speed-of-sound transmission, are indicative of wood decay (Pellerin et al. 1985) . The pattern of gradually increasing transmission times at the ends of the respective members and progressive movement of increased transmission time internally from the ends with increased exposure suggests that decay becomes established at the ends and then progresses inward toward the center. Decay does not become universally established simultaneously along the length of the member.

Knowledge of the rate at which brown-rot fungi move through wood used in buildings could expedite the assessment of damage to construction where decay is known to occur. Unfortunately, little information on rate of growth within wood is available. Within simulated wall cavities, Thornton and Johnson (1986) observed Serpula lacrymans growing over wood surfaces at a rate of 9.0 mm per day. Results from this study show that progression of naturally occurring, predominantly brown-rot decay fungi in exposed, unrestrained members is slow. Furthermore, a substantial time is needed before weight loss throughout the length of the members can be observed for the population of members that were exposed. We assumed that at 21 months of exposure, when the first substantive increment in group mean stress wave time was observed (Fig. 10), important losses in mechanical properties of the exposed wood had occurred. The increased skewness of distribution curves for both percentage weight loss (Fig. 5) and sound transmission time with increased exposure suggests that the rate of decomposition within individual members accelerates as the decay fungus becomes widely distributed within each member.

The rate at which decay is established at the ends is perhaps the most important factor. Ends of wood members are usually fastened and contribute to the engineering properties of joints. Furthermore, a definition of the critical dimensions needed to provide a realistic simulation of actual construction seems cardinal to developing a truly quantifiable technique that evaluates wood protection options for above-ground application. We intend to address this issue at the conclusion of the study. At that time, all members will be destructively compressed. Upon completion of compression tests, we plan to section these members in an attempt to analyze the rate of decay in segments of the members.

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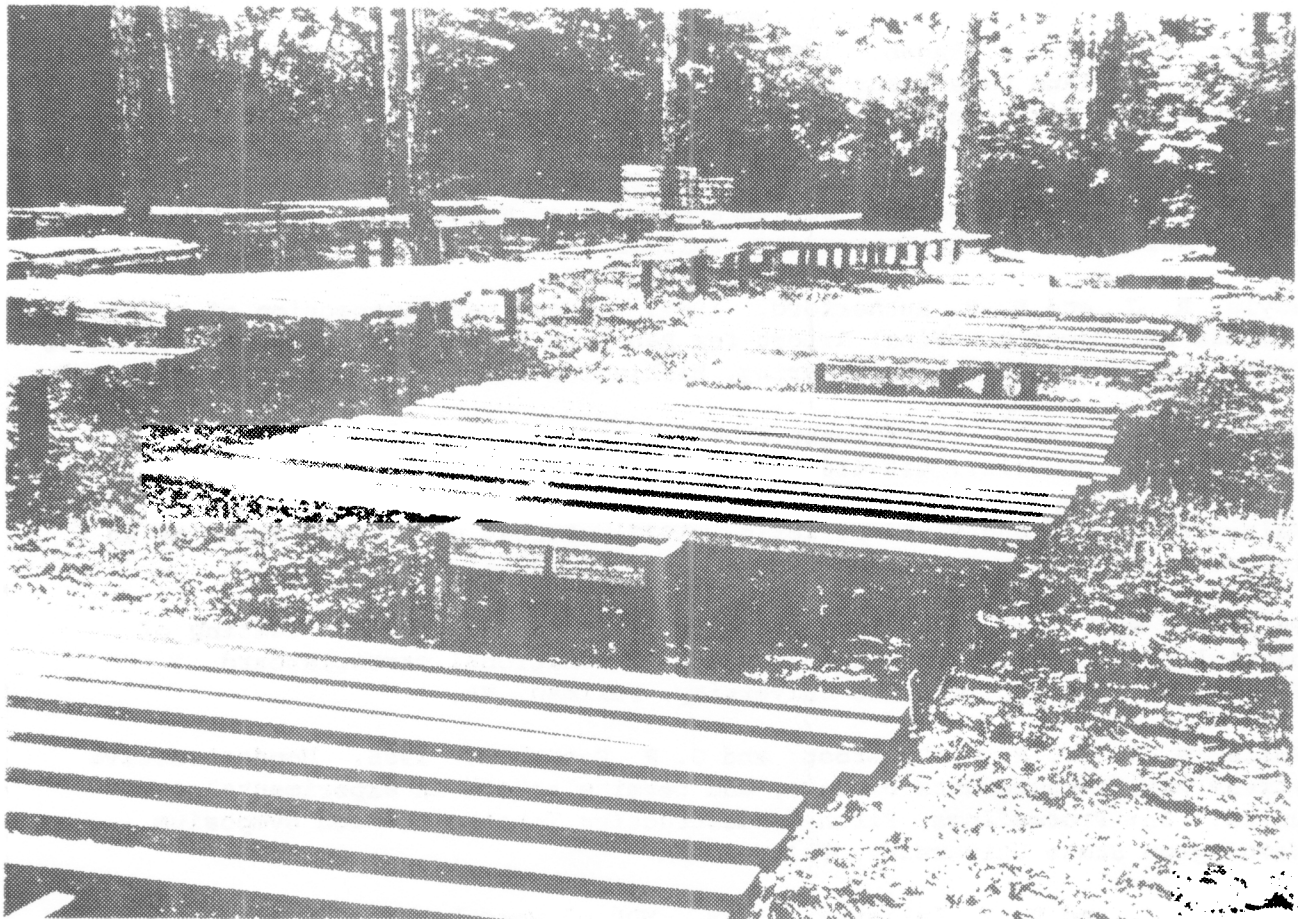

Figure 1. Field Site.

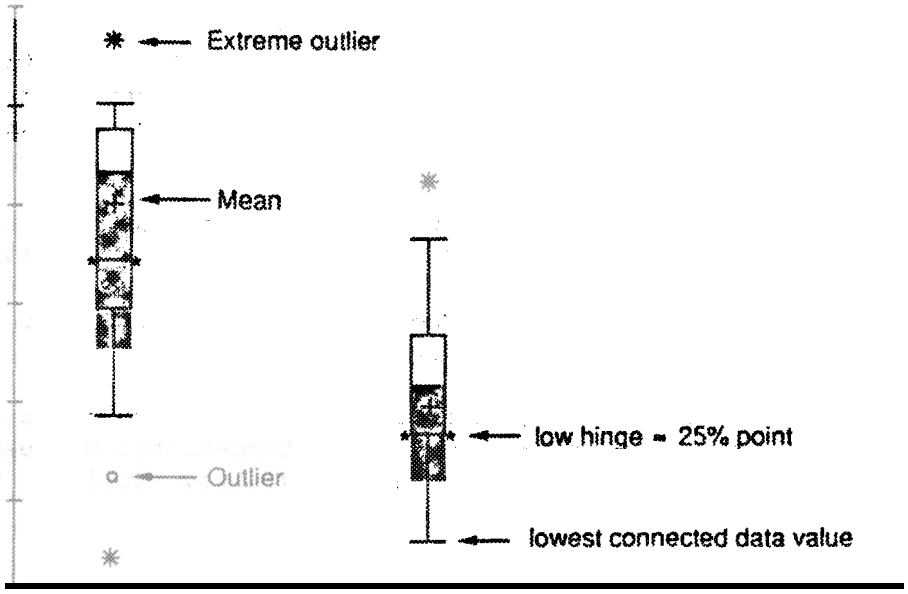

Figure 2. Boxplot components. Shaded area is 95% confidence interval test of equality of medians.

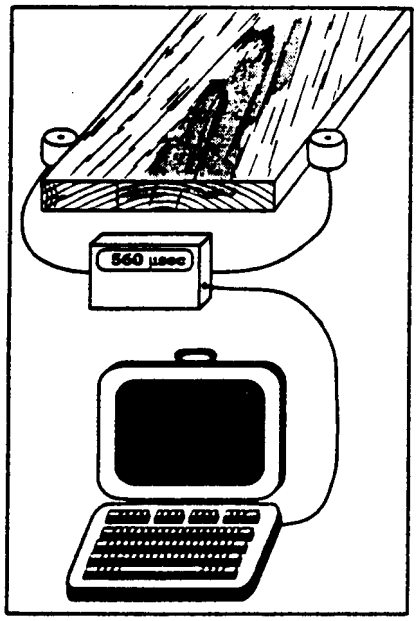

Figure 3. Setup used to measure speed of sound through transverse direction of wood members.

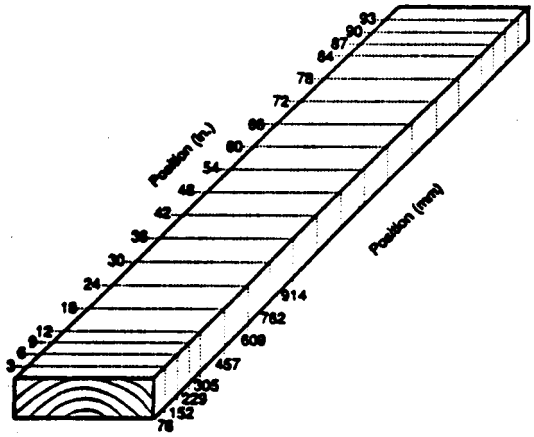

Figure 4. Positions at which speed-of-sound transmission in the transverse direction were measured along the length of each member.

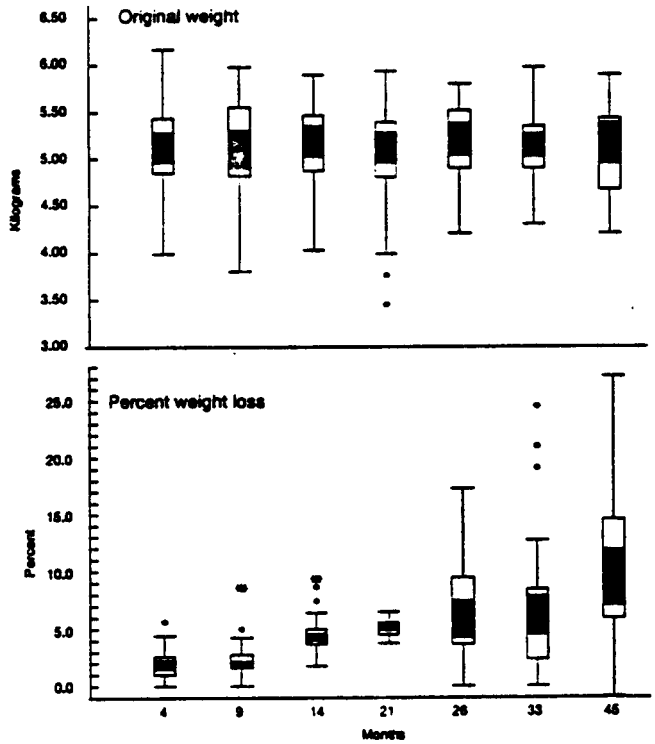

Figure 5. Distribution of original weight within each group prior to exposure and percentage weight loss after exposure in the field.

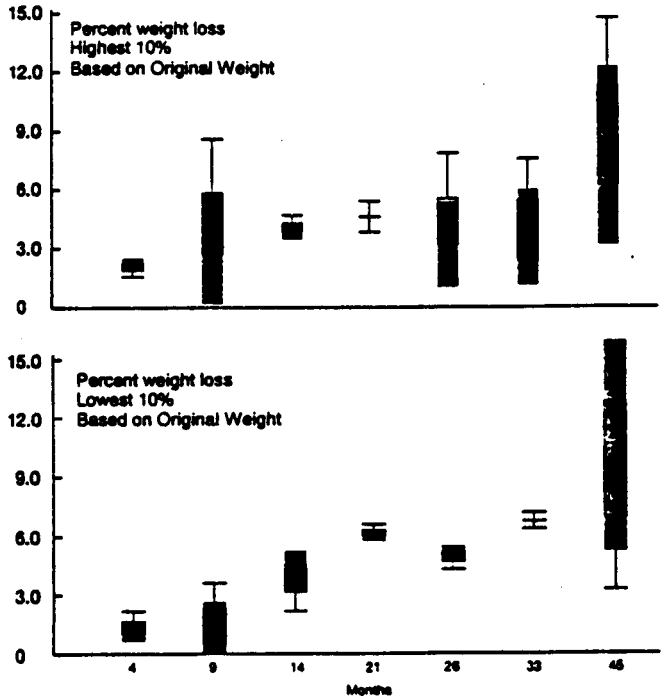

Figure 6. Percentage weight loss as a result of decay in either the heaviest or lightest three members within each respective group after field exposure.

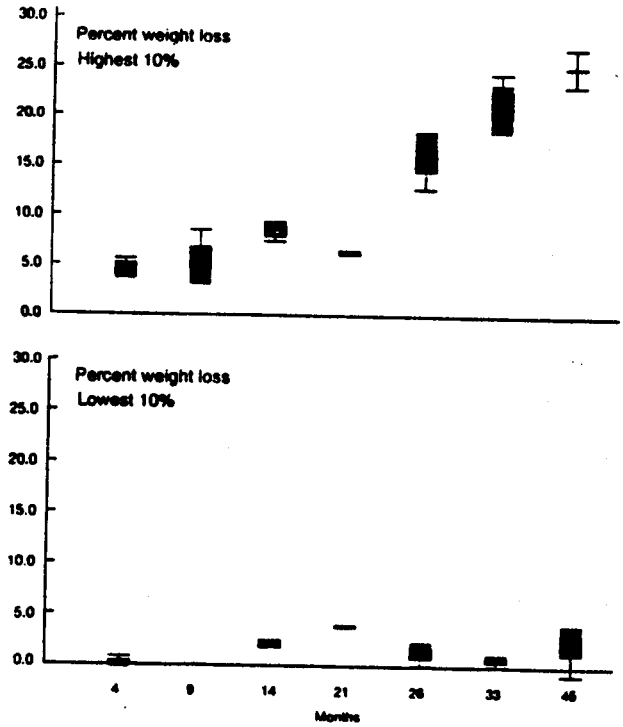

Figure 7. Distribution of percentage of weight loss observed in the three members at each exposure interval that had the most or least weight loss.

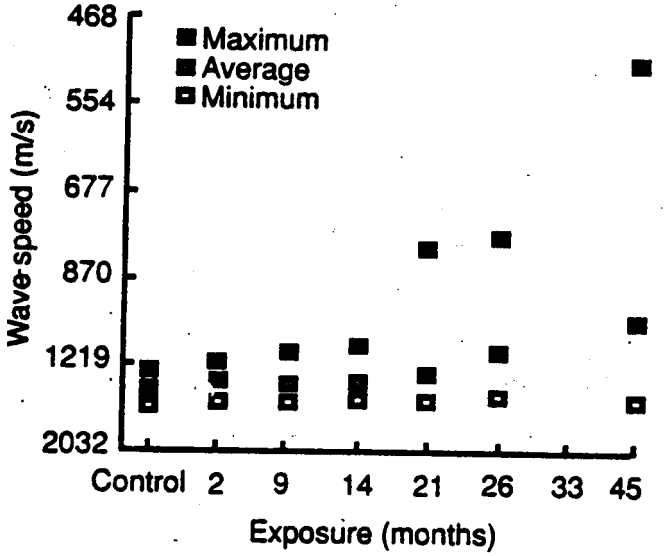

Figure 8. Distribution of sound transmission speeds for members within each exposure interval.

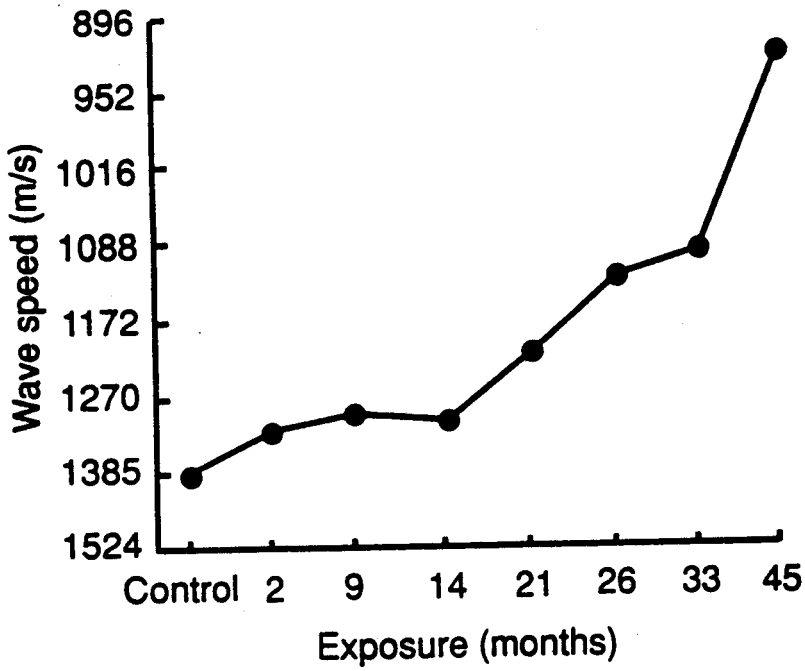

Figure 9. Mean sound transmission speed for representative groups after exposure in the field for the duration indicated.

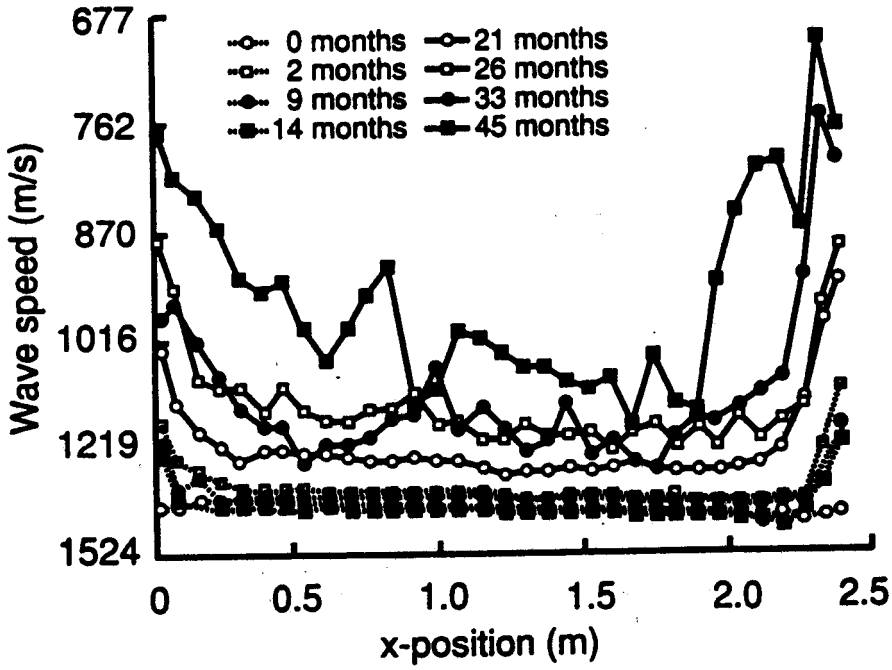

Figure 10. Mean sound transmission speed in transverse direction at each location along length of member within each exposure group.

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