MECHANICAL PROPERTIES OF SMALL CLEAR SPECIMENS AND VISUALLY GRADED LUMBER FROM LIVING AND SPRUCE BUDWORM-KILLED BALSAM FIR

Douglas P. Barnes and *Steven A. Sinclair*

Research Associate and Associate Professor
Department of Forest Products, School of Forestry and Wildlife Resources
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

and

Robert L. Govett

Assistant Professor
Department of Forest Products, University of Idaho
Moscow, ID 83843

(Received June 1983)

ABSTRACT

Small clear specimens from living balsam fir and from spruce budworm-killed balsam fir dead 3 months, 12 months, and 22 months were tested in bending and compression perpendicular to the grain. Results indicated that modulus of rupture (MOR) of specimens from budworm-killed trees dead 3 months or more was significantly lower than MOR of specimens from living trees. Modulus of elasticity (MOE) appeared to be less sensitive to changes in budworm-killed material than MOR. Stress at the proportional limit for compression perpendicular to the grain was significantly lower for specimens from trees dead 22 months than for specimens from living trees. Both MOE and MOR in bending were determined for visually graded nominal 2- by 4-inch lumber from living and spruce budworm-killed balsam fir dead 12 months and 22 months. Average MOE values for living balsam fir were 1.274×10^6 psi, 1.217×10^6 psi, and 1.175×10^6 psi for Construction, Standard and Utility grades, respectively. Average MOR values for the same grades of living material were 4,699 psi, 4,684 psi, and 4,352 psi, respectively. Average MOE and MOR for Utility grade lumber from both spruce budworm-killed categories were not significantly different from the average MOE and MOR for living balsam fir. Statistical analyses of the MOE and MOR data for Construction and Standard grades of budworm-killed lumber were not performed due to the small sample sizes.

Keywords: Balsam fir, spruce budworm, mechanical properties, dimension lumber, static bending, compression perpendicular to the grain.

INTRODUCTION

For 1982 alone, Kucera and Orr (1983) report that tree mortality of balsam fir (*Abies balsamea* (L.) Mill.) had occurred on over 1.6 million acres in the eastern United States due to defoliation by the spruce budworm (*Choristoneura fumiferana* Clem.). Continuing losses of balsam fir due to spruce budworm attacks have increased the demand for additional information on the utilization of living and spruce budworm-killed balsam fir. In response to this demand, several recent balsam fir utilization studies have been completed (Fereshtehkhou 1982; Govett 1982; Hatton 1982; Hughes 1981; Minerowicz et al. 1982). Living and spruce budworm-killed balsam fir were evaluated as a raw material for use in dimension lumber, composite wood products, and paper products. Generally, it was shown that living balsam fir provides a raw material suitable for a variety of end products.

Wood and Fiber Science, 17(1), 1985, pp. 36–46

In addition, spruce budworm-killed balsam fir was also successfully used in certain products, especially when using material from trees dead 1 year or less.

An early study of the mechanical properties of a very limited sample of living balsam fir was published in 1935 by Markwardt and Wilson. The results of this study were used until a reexamination of the mechanical properties of small clear specimens from living balsam fir was conducted by Bendtsen (1974). The main purpose of the latter study was to reevaluate mean and variability estimates for the development of allowable design stresses. However, no information is available to determine what changes may occur in the mechanical properties of budworm-killed balsam fir. Therefore, the objective of this study was to evaluate selected mechanical properties of spruce budworm-killed balsam fir and to compare these properties to those of living balsam fir.

It has been suggested that living balsam fir has the potential for increased use as dimension lumber (Bowyer et al. 1982; Govett 1982); however, reported results on mechanical tests of full-size specimens of balsam fir dimension lumber are limited. Huffman (1977) studied the effects of high temperature drying on the stiffness and strength of balsam fir joists. Nominal 2- by 6-inch lumber was subjected to conventional and high temperature drying schedules. For lumber graded No. 2 and Better after drying, modulus of elasticity (MOE) for green and kiln-dry and the modulus of rupture (MOR) for kiln-dry balsam fir were reported for both drying schedules. In another study, MOE and MOR were reported for nominal 2- by 4-inch balsam fir members subjected to various predrilling treatments to improve the drying rate (Anthony et al. 1973).

The continuing destruction by the spruce budworm has spurred a renewed interest in utilizing both living and budworm-damaged balsam fir. With the suggested increased utilization of balsam fir for dimension lumber, it is of interest to better characterize the mechanical properties of this species. This is particularly important for nominal 2- by 4-inch sized material, which in a recent survey comprised over half of the reported balsam fir lumber production from 144 sawmills in eastern North America (Sinclair and Govett 1983).

MATERIALS AND METHODS

Field plots of budworm-damaged balsam fir were established in the summer of 1979 in St. Louis County, Minnesota. Individual trees were identified prior to death, and external tree characteristics were observed to determine the date of tree death. These observations were made monthly from early spring through late fall for three consecutive years. Observable characteristics followed the pattern reported by Belyea (1952) with cambial discoloration representing the point of death. The observation procedure is described in detail by Govett (1982).

Small clear specimens

Sinclair et al. (1979) found a greater reduction in the toughness of small clear specimens taken from top logs of beetle-killed southern pine trees than from corresponding butt logs. To determine if mechanical properties of budworm-killed balsam fir might follow the same pattern, six consecutive 50-inch bolts, starting at the tree base, were harvested for each of the nine living (control) trees, six trees dead 3 months, five trees dead 12 months, and six trees dead 22 months. This simulated the harvest of three 100-inch sawbolts while allowing for greater ease in transporting the material from the field to the laboratory. The first ten growth rings were identified and color-coded on both ends of each bolt to help avoid juvenile wood in test specimen preparation.

Bolts from the harvested trees were converted to lumber and subsequently air-dried. Prior to machining the final specimen dimensions, the lumber was conditioned to a target moisture content of 12% (oven-dry basis). Small clear test specimens were machined from the air-dried lumber. The color-coded growth rings, stain, decay and insect holes were carefully avoided during specimen preparation. Two compression and bending specimens, meeting the above requirements, were selected from each 50-inch bolt . In some cases, trees having extreme heartrot for example, only one specimen per 50-inch bolt for each test could be obtained for testing purposes. All machined specimens were reconditioned to the same target moisture content of 12% (oven-dry basis) prior to testing.

Both static bending and compression perpendicular to the grain tests were performed on the small clear specimens following ASTM Standard D 143-52 (1981a). Static bending specimens measuring 1- by 1- by 16-inches were destructively tested over a 14-inch span. Center point loading at a crosshead speed of 0.05 inches per minute was employed during this test.

Compression specimens with dimensions of 1- by 1- by 4-inches were tested with the load applied across the entire radial width of the specimen at a rate of 0.012 inches per minute. The compression test was discontinued after 0.1 inch of deflection in compression and the proportional limit stress value was calculated from the results of this test. The compression specimens' dimensions in this study were not the same as the dimensions specified for compression specimens in ASTM Standard D 143-52 (1981a) because of the difficulty in machining 2- by 2- by 6-inch clear specimens from small bolts.

Small blocks were cut from all specimens near the zone of failure to determine specific gravity, which was calculated on an oven-dry weight/green volume basis using a water displacement technique to determine green volume.

Analysis of covariance, using tree categories and specimen height in tree as the main classifications, was performed on the data. In the analysis, the averages of the mechanical properties were adjusted for differences in specimen specific gravity. Duncan's multiple range test (Steel and Torrie 1960) was used at a 95% confidence level to separate the adjusted averages when the analysis of covariance test indicated significant differences existed.

Full size specimens

The full size test material consisted of nominal 2- by 4-inch lumber, having Utility grade or Better, from a previously reported grade yield study in Minnesota (Govett 1982). Lumber from living and spruce budworm-killed balsam fir was selected for testing. The budworm-killed material was sawn from trees standing dead 12 months and 22 months.

The full size specimens[1] received green from the sawmill were stickered and allowed to air-dry in the laboratory. These air-dried specimens were then milled to their final cross-sectional dimension of 1½ by 3½ inches and graded according

[1] Actual green specimen dimensions were approximately 2- by 4- by 100-inches.

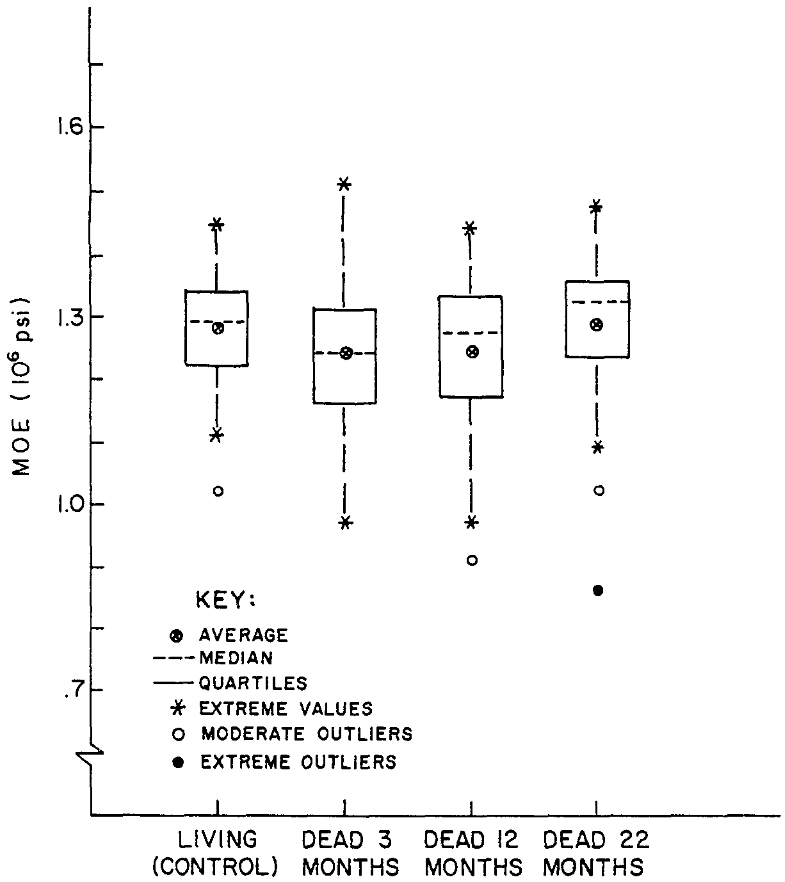

FIG. 1. Modulus of elasticity from small clear specimens of living and budworm-killed balsam fir.

to the Standard Grading Rules of the Northern Hardwood and Pine Manufacturers Association (NH & PMA 1979) by a Chief Inspector of that association. Cross-sectional dimension measurements were obtained from third points and the center point of an 87-inch span. These three measurements were averaged for use in the MOE and MOR calculations published in ASTM Standard D 198-76 (1981b). A two-point load was applied to a randomly chosen narrow edge of each test specimen at a rate of 0.4 inches per minute. Deflection of the specimens was measured at the center of the 29-inch span between the two load points. All material was conditioned to a target moisture content of 12% (oven-dry basis) prior to testing.

A modified Kolmogorov-Smirnov goodness of fit procedure (Pettitt and Stephens 1977) was used to test the data from each tree category for normality at a 0.05 level of significance. This test showed certain tree categories to have non-normal sample distributions, therefore, the Kruskal-Wallis procedure (1952) was used to test for statistical differences in MOE and MOR between tree categories for Utility grade lumber. Statistical tests were not performed for the other lumber grades because of the small sample sizes which resulted from low yields of Construction and Standard grades from budworm-killed trees. The nonparametric

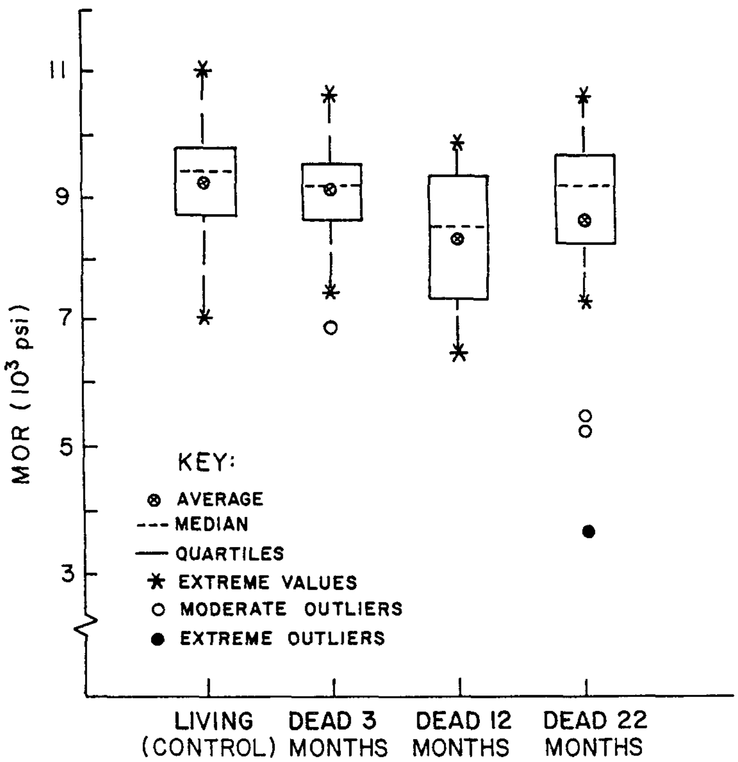

FIG. 2. Modulus of rupture from small clear specimens of living and spruce budworm-killed balsam fir.

estimate of the 5% exclusion limit was calculated using ASTM Standard D 2915-74 (1982).

RESULTS

Small clear specimens

The data from the small clear static bending specimens for each balsam fir tree category are presented in the form of box-whisker plots (Figs. 1, 2). Such plots are used to display the range, median, and a rough measure of the skewness for a sample distribution (Tukey 1977). The upper and lower lines of each box indicate the 25th and 75th percentiles, and the broken line within each box indicates the location of the median. The average values for each tree category are located within each box, and the extreme values for the distributions are identified by the asterisks at the end of the vertical broken lines.

MOE average for living balsam fir was 1.278×10^6 psi and ranged from 1.236×10^6 psi to 1.282×10^6 psi for budworm-killed balsam fir. MOR average for living balsam fir was 9,284 psi and ranged from 8,276 psi to 9,057 psi for budworm-killed material. For the purpose of comparison, Bendtsen (1974) reported an MOE average for living balsam fir of 1.452×10^6 psi and an MOR average of 9,171 psi.

Since specific gravity is known to influence mechanical properties, it was decided

TABLE 1. *Modulus of elasticity (MOE) and modulus of rupture (MOR), adjusted to a specific gravity of 0.320, from small clear specimens of living and spruce budworm-killed balsam fir.*

Tree category	Ave. MOE (10^6 psi)	Significance of MOE*	Ave. MOR (psi)	Significance of MOR*	Number of specimens
Living	1.302	A	9,476	A	48
Dead 3 months	1.244	B	8,994	B	27
Dead 12 months	1.245	B	8,367	C	29
Dead 22 months	1.286	AB	8,554	C	29

* Adjusted averages having the same letter were not significantly different using Duncan's Multiple Range Test at a 95% confidence level.

to remove the differences between specimens by using specific gravity as a covariate in the statistical analysis. An initial analysis of the data included tree categories, height in tree, and the interaction of tree categories and height in tree as main effects in the statistical models. The interaction term was statistically insignificant, which indicated that the variation in MOE and MOR within tree categories was independent of height in tree. Therefore, the interaction term was removed from the statistical models. The resulting models, used to statistically analyze MOE and MOR, were both highly significant ($\alpha < 0.001$).

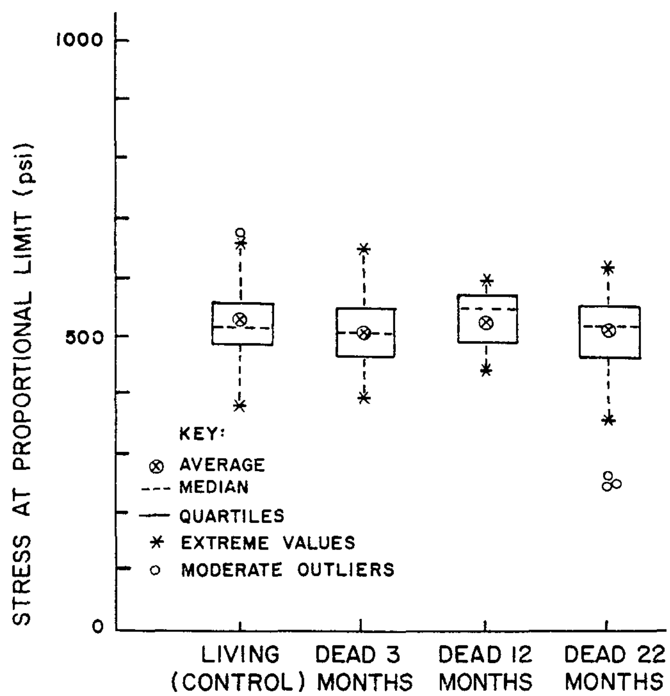

FIG. 3. Stress at proportional limit from compression perpendicular to the grain specimens of living and spruce budworm-killed balsam fir.

Table 1 presents the results after adjusting the MOE and MOR to the average specific gravity of the tree categories. The adjusted MOE for living balsam fir was 1.302×10^6 psi and ranged from 1.244×10^6 psi to 1.286×10^6 psi for the dead material. Duncan's procedure showed that the adjusted MOE from the living tree category was significantly higher than the adjusted MOE from trees dead 3 months and 12 months. However, the adjusted MOE for trees dead 22 months was not significantly different from living trees or trees dead 3 months and 12 months. It is difficult to explain the high adjusted MOE for trees dead 22 months; however, the possibility exists that different rates of undetectable decay occurred between the tree categories because of individual tree location in the forest or season of tree death. Small numbers of specimens did not allow the analysis of these possibilities.

Table 1 also shows the results for adjusted MOR from each tree category. Specimens from the living tree category exhibited an adjusted MOR of 9,476 psi, which was statistically higher than any dead tree category adjusted MOR. Additionally, the adjusted MOR of specimens from trees dead 3 months was significantly higher than the adjusted MOR's for tree categories of dead 12 months and dead 22 months.

Compression

Data for compression perpendicular to the grain specimens for each tree category are shown in Fig. 3. Tree category proportional limit averages ranged from 505 psi to 534 psi.

Statistical analysis of the data was performed using the same covariance model used in analyzing the bending properties. Again, the interaction term of tree categories and height in tree was not statistically significant. The model, using tree categories and height in tree as the main effects, was found to be highly significant ($\alpha < 0.001$). Table 2 presents the stress at proportional limit from specimens of living and spruce budworm-killed balsam fir. The values were adjusted to the average specific gravity of the tree categories. Specimens from living trees had an average adjusted stress at proportional limit of 544 psi, and the dead tree categories' average stress at proportinal limit ranged from 488 psi to 529 psi. Duncan's mean separation procedure indicated specimens from trees dead 22 months were significantly lower than specimens from living trees.

Full size specimen

Results of the static bending tests are presented in Tables 3 and 4. Both MOE and MOR are given for the structural grades of lumber from both living and budworm-killed balsam fir.

Living balsam fir

The MOE averages for Construction, Standard, and Utility grades of lumber from living balsam fir were 1.274×10^6 psi, 1.217×10^6 psi, and 1.175×10^6 psi, respectively. These values are very close to the recommended MOE design value[2] for balsam fir published by the NH & PMA (1979). Anthony et al. (1973)

[2] The recommended MOE design value for balsam fir lumber graded under the NH & PMA light framing rules is 1.2×10^6 psi for Construction, Standard and Utility grades (1979).

TABLE 2. *Stress at proportional limit, adjusted to a specific gravity of 0.320, from compression perpendicular to the grain specimens for living and spruce budworm-killed balsam fir.*

Tree category	Stress at proportional limit (psi)	Significance of stress at proportional limit	Number of specimens
Living	544	A	55
Dead 3 months	506	AB	23
Dead 12 months	529	A	30
Dead 22 months	488	B	30

* Adjusted averages having the same letters were not significantly different using Duncan's Multiple Range Test at a 95% confidence level.

reported an average MOE value of 1.31×10^6 psi for dry balsam fir members with nominal cross-section dimensions of 2- by 4-inches. Huffman (1977) reported the average MOE of No. 2 and Better nominal 2- by 6-inch joists of dry balsam fir to be 1.26×10^6 psi. These values can be compared to the MOE values given in Tables 1 and 3.

The Construction and Standard grades of lumber from living trees had average MOR values of 4,699 psi and 4,684 psi, respectively. These values are similar to the MOR of 4,670 psi reported for nominal 2- by 4-inch balsam fir members (Anthony et al. 1973). The Utility grade, in this study, exhibited an average MOR of 4,352 psi. The nonparametric estimate of the 5% exclusion limit was calculated for each grade of lumber from living balsam fir (ASTM Standard D 2915-74 1982) and is given in Table 4. The exclusion limit estimates (given in Table 4) should not be used to represent the entire balsam fir population since all the specimens were sampled from a specific geographic location (St. Louis County, Minnesota).

Budworm-killed balsam fir

The MOE and MOR averages from a limited sample of Construction and Standard grades of lumber from budworm-killed trees are also given in Tables 3 and 4, respectively. A larger number of samples is needed to provide confidence in the estimates presented for the Construction and Standard grades.

Utility grade lumber from budworm-killed balsam fir had MOE averages of 1.155×10^6 psi and 1.173×10^6 psi for material dead 12 months and 22 months,

TABLE 3. *Modulus of elasticity for nominal 2- by 4-inch visually graded lumber from living and budworm-killed balsam fir.*

Tree category	Grade[1]	Average MOE (10^6 psi)	Standard deviation (10^6 psi)	Sample size
Living (control)	Construction	1.274	0.1772	108
	Standard	1.217	0.1950	78
	Utility	1.175	0.1900	101
Dead 12 months	Construction	1.364	0.2784	5
	Standard	1.191	0.1410	21
	Utility	1.155	0.1836	87
Dead 22 months	Construction	1.199	0.2749	6
	Standard	1.119	0.1495	3
	Utility	1.173	0.1680	65

[1] Light framing grades under the Standard Grading Rules of the Northern Hardwood and Pine Manufacturers Association (1979).

TABLE 4. *Modulus of rupture for nominal 2- × 4-inch visually graded lumber from living and budworm-killed balsam fir.*

Tree category	Grade[1]	Average MOR (psi)	Standard deviation (psi)	Sample size	Nonparametric estimate of the 5% exclusion limit[2] (psi)
Living	Construction	4,699	1,145	108	2,877
(control)	Standard	4,684	1,539	78	2,626
	Utility	4,352	1,355	101	2,134
Dead 12	Construction	5,408	1,295	5	–
months	Standard	4,400	936	21	–
	Utility	4,273	1,243	87	2,354
Dead 22	Construction	4,647	1,001	6	–
months	Standard	4,036	491	3	–
	Utility	4,127	986	65	2,679

[1] Light framing grades under the Standard Grading Rules of the Northern Hardwood and Pine Manufacturers Association (1979).
[2] Calculated using procedures in ASTM Standard D 2915–74 (1982).

respectively (Table 3). These values are comparable to the MOE for Utility grade lumber from living balsam fir and are close to the recommended MOE design value.

Average MOR values for Utility grade lumber from budworm-killed balsam fir were 4,273 psi and 4,127 psi for material from trees dead 12 months and 22 months, respectively (Table 4). The 5% exclusion limit was only presented for Utility grade lumber from budworm-killed balsam fir (Table 4) because of small sample sizes in the Construction and Standard grades.

COMPARISON OF LIVING AND BUDWORM-KILLED BALSAM FIR

Since the Kolmogorov-Smirnov goodness of fit test indicated that at least one tree category had non-normally distributed data, MOE vaues for Utility grade lumber from each tree category were statistically compared using the Kruskal-Wallis test. The results of this test ($\alpha = 0.81$) did not give enough evidence to confidently reject the hypothesis of equal MOE values for each tree category.

Similarly, statistical comparison of MOR values from Utility grade lumber did not reveal any significant differences between living and dead tree categories. There was not sufficient evidence ($\alpha = 0.57$) of statistically significant differences to confidently reject the hypothesis of equal MOR values for each tree category.

CONCLUSIONS

Small clear specimens

1. Bending test results were inconsistent in revealing statistically significant decreases in the adjusted MOE's of the budworm-killed tree categories; however, the adjusted MOR's for all budworm-killed categories were significantly lower than the adjusted MOR for the living tree category.

2. Similar to MOE, compression perpendicular to the grain appeared to be less sensitive to changes in budworm-killed material than MOR. Results of the compression test indicated that significant reductions in the adjusted stress at proportional limit did not occur until trees were dead 22 months, but even then

there was no statistical difference between the dead 3 months and dead 22 months categories.

3. These results suggest that statistically significant reductions in certain mechanical properties of small clear specimens from spruce budworm-killed balsam fir can occur in the absence of visually observable characteristics such as decay, stain, or insect holes.

Full size specimens

Construction and Standard lumber grade yields from budworm-killed balsam fir were very low, and too few test specimens were available to make any confident conclusions concerning their mechanical properties. However, for the Utility grade from trees dead 12 months and 22 months and for Construction, Standard, and Utility grades from living trees, the following conclusions can be drawn:

1. The MOE averages for Construction, Standard, and Utility grades of lumber from the living tree category were very near the MOE design value recommended by the NH & PMA.

2. The average MOE values for Utility grade lumber from trees dead 12 months and 22 months were close to the MOE design values suggested by NH & PMA.

3. Statistical comparisons of the data from Utility grade lumber indicated that no significant differences existed between the living and budworm-killed balsam fir dead 12 and 22 months for MOE and MOR properties.

ACKNOWLEDGMENTS

The authors wish to thank Charles Evenson, Mark Sweazy, and Harold Vandivort for their assistance during this project. Financial support was provided by the USDA program entitled "Canada-United States Spruce Budworms Program" (CANUSA) Grant 23-626, and the College of Forestry, University of Minnesota.

REFERENCES

American Society for Testing and Materials. 1981. Testing small clear specimens of timber. ASTM D 143-52. Philadelphia, PA.

———. 1981b. Static tests of timbers in structural sizes. ASTM D 198-76. Philadelphia, PA.

———. 1982. Evaluating allowable properties for grades of structural lumber. ASTM D 2915-74. Philadelphia, PA.

Anthony, R., R. W. Erickson, and J. Haygreen. 1973. Drying and strength characteristics of predrilled balsam fir studs. Paper No. 8360 in the Scientific Journal of the Agricultural Experimental Station, University of Minnesota.

Belyea, R. M. 1952. Death and deterioration of balsam fir weakened by spruce budworm defoliation in Ontario. The Can. Ent. 84(11):325–335.

Bendtsen, B. A. 1974. Specific gravity and mechanical properties of black, red, and white spruce and balsam fir. USDA Forest Serv. Res. Pap. FPL 237. Madison, WI.

Bowyer, J. L., S. A. Sinclair, P. V. Sibal, and R. L. Govett. 1982. Balsam fir—A potential new source of softwood lumber. For. Prod. J. 32(1):53–58.

Fereshtehkhou, S. 1982. The properties of pulp and paper from spruce budworm-killed balsam fir. M.S. thesis, University of Minnesota, Department of Forest Products, St. Paul, MN.

Govett, R. L. 1982. The potential for increased utilization of spruce budworm threatened, damaged, or killed balsam fir in the production of dimension lumber. Ph.D. thesis, University of Minnesota, Department of Forest Products, St. Paul, MN.

Hatton, J. V. 1983. Making the most of budworm-killed wood. *In* Proc. of the Canadian Pulp and Paper Association, Technical Section, 69th Annual Meeting, Montreal, Quebec.

HUGHES, M. T. 1981. Waferboard and flakeboard from healthy and spruce budworm-killed balsam fir. M.S. thesis, University of Minnesota, Department of Forest Products, St. Paul, MN.

HUFFMAN, D. R. 1977. High-temperature drying effect on the bending strength of spruce-pine-fir joists. For. Prod. J. 27(3):55–57.

KRUSKAL, W. H., AND W. A. WALLIS. 1952. Use of ranks in one-criterion variance analysis. J. Amer. Statist. Assoc. 47:583–621.

KUCERA, D., AND P. ORR. 1983. Spruce budworm conditions in the United States 1982. CANUSA Newsletter, No. 27, March 1983:1–3.

MARKWARDT, L. S., AND T. R. C. WILSON. 1935. Strength and related properties of woods grown in the United States. USDA Tech. Bull. 479.

MINEROWICZ, E. A., D. A. GAUVIN, M. KAGALWALA, M. K. HILL, AND J. M. GENCO. 1982. Pulping budworm-killed balsam fir. LSA Bulletin 786, University of Maine, Orono, ME.

NORTHERN HARDWOOD AND PINE MANUFACTURERS ASSOCIATION, INC. 1979. Standard grading rules. 1979 (rev.), Green Bay, WI.

PETTITT, A. N., AND M. A. STEPHENS. 1977. The Kolmogorov-Smirnov goodness-of-fit statistic with discrete and grouped data. Technometrics 19(2):205–210.

SINCLAIR, S. A., AND R. L. GOVETT. 1983. Production and distribution of balsam fir lumber in eastern North America. Forestry Chronicle 59(6):128–131.

———, T. E. MCLAIN, AND G. IFJU. 1979. Toughness of sap-stained southern pine. Wood Fiber 11(1):66–72.

STEEL, R. G. D., AND J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York.

TUKEY, J. W. 1977. Exploratory data analysis. Addison-Wesley Pub. Co., Reading, MA.