MOISTURE CONTENT AND THE FLEXURAL PROPERTIES OF LUMBER: SPECIES DIFFERENCES

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Results are presented on the influence of moisture content (MC) on the flexural properties of lumber produced from several species. Preview research with Douglas-fir and Southern Pine has shown that the change in modulus of rupture (MOR) with change in MC is a function of lumber quality and does not necessarily increase with decreasing MC. Similar results have now been obtained for sugar pine and western white pine. The MOR of black spruce and grand fir was found to increase with decreasing MC except for the lowest quality material. The MOR of eastern hemlock was found to be somewhat insensitive to change in MC. The modulus of elasticity (MOE) of all species except eastern hemlock exhibited an increase in MOE with decreasing MC.

INTRODUCTION

Over the past 10 years, a considerable amount of work has been conducted at or in cooperation with the USDA Forest Service, Forest Products Laboratory, on the effect of moisture content (MC) on the mechanical properties of standard 38-mm- (nominal 2-in.-) thick structural lumber (5). These studies have shown that the change in properties with the change in MC is a function of lumber quality and that strength does not necessarily increase with decreasing MC (Fig. 1). Previous studies have produced new analytical models for relating lumber properties to change in MC (3). Simplified models for incorporating this information into engineering design standards have also recently been approved (D 1990) (l). These simplified models are being applied to all species. However, the research on which these models are based utilized test results from only two species: Douglas-fir and Southern Pine (2,6). Both these species are relatively high-density species with abrupt transition between earlywood and latewood. Lumber cut from both species may contain relatively large knots. No compatible data on species other than Douglss-fir and Southern Pine exist to judge the applicability of these standardized models.

The objective of this paper is to present the results of a study on the effect of change in MC on the bending properties of lumber for five additional species. This study is limited to standard 38- by 89-mm (nominal 2- by 4-in.) lumber of two grades. A future paper will evaluate the applicability of analytical models recently adopted in engineering design standards to these species.

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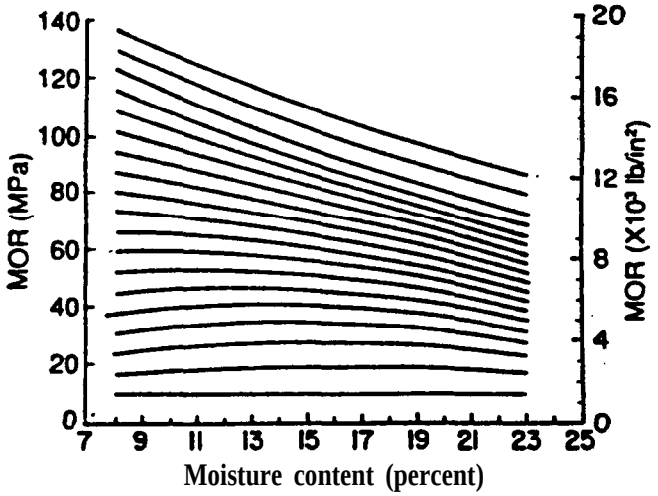

Figure 1 Analytical model of the effect of moisture content on bending propeties (6).

EXPERIMENTAL PROCEDURES

Selection of species to test was based primarily on the effect of MC on the bending properties of clear wood (4). It had previously been shown that trends in the dry-green relationship for most species follow one trend line, while a few species are less sensitive to change in MC and follow another trend line (Fig. 2a). Most of the less-sensitive species have higher extractive contents. To evaluate species for this study, the dry-green ratios were plotted as a function of their green MCs (Fig. 2b). The species that make up the commercial groupings Douglas Fir-Larch and Southern Pine are circled in Figure 2b. As an initial hypothesis, it was assumed that moisture adjustment procedures derived from data on Douglas-fir and Southern Pine would be applicable to all species within the indicated dry-green ratio bands. Black spruce (Picea mariana) and sugar pine (Pinus lambertiana) were selected as weaker species that are within the dry-green ratio band (15 and 30, respectively, Fig. 2b). Western white pine (Pinus monticola) was selected as a species above the band (species more sensitive to moisture change, 27). Grand fir (Abies grandis, 23, Fig. 2b) was selected as representative of species slightly below the band but not one of the species on the lower regression line in Figure 2a. Although on the lower trend line in Figure 2a, eastern hemlock (Tsuga canadensis) was included because no obvious reason could be found why it was less sensitive to change in MC.

Lumber for this study was selected from production inventory at lumber mills. The lumber was sampled in the green condition, wrapped, and shipped to Washington State University, Pullman, Washington, for testing. Two grades, Select Structural (SS) and No. 2, were selected to provide a range of quality levels. The lumber was selected to be “on grade” based on characteristics that affect strength (e.g., appearance characteristics such as wane were not considered).

The objective of the sorting procedure was to obtain three sample populations for each species and grade that were “matched” in terms of their estimated green strength and stiffness. Modulus of elasticity (MOE) in the flatwise orientation and strength ratio were used to match the samples in the green condition. Once matched, each of the three groups was then randomly assigned to one of three moisture categories--green, 15%, or 10%. The target sample size for each MC-species-grade combination was 50. However, about 55 pieces were assigned to each group to allow for damage in handling and degrade as a result of drying.

It is recognized that final lumber quality is dependent upon the severity of the kiln schedule used in drying the lumber as well as on initial lumber quality. To match drying conditions used in the Douglas-fir and Southern Pine studies, the green lumber to be dried to the

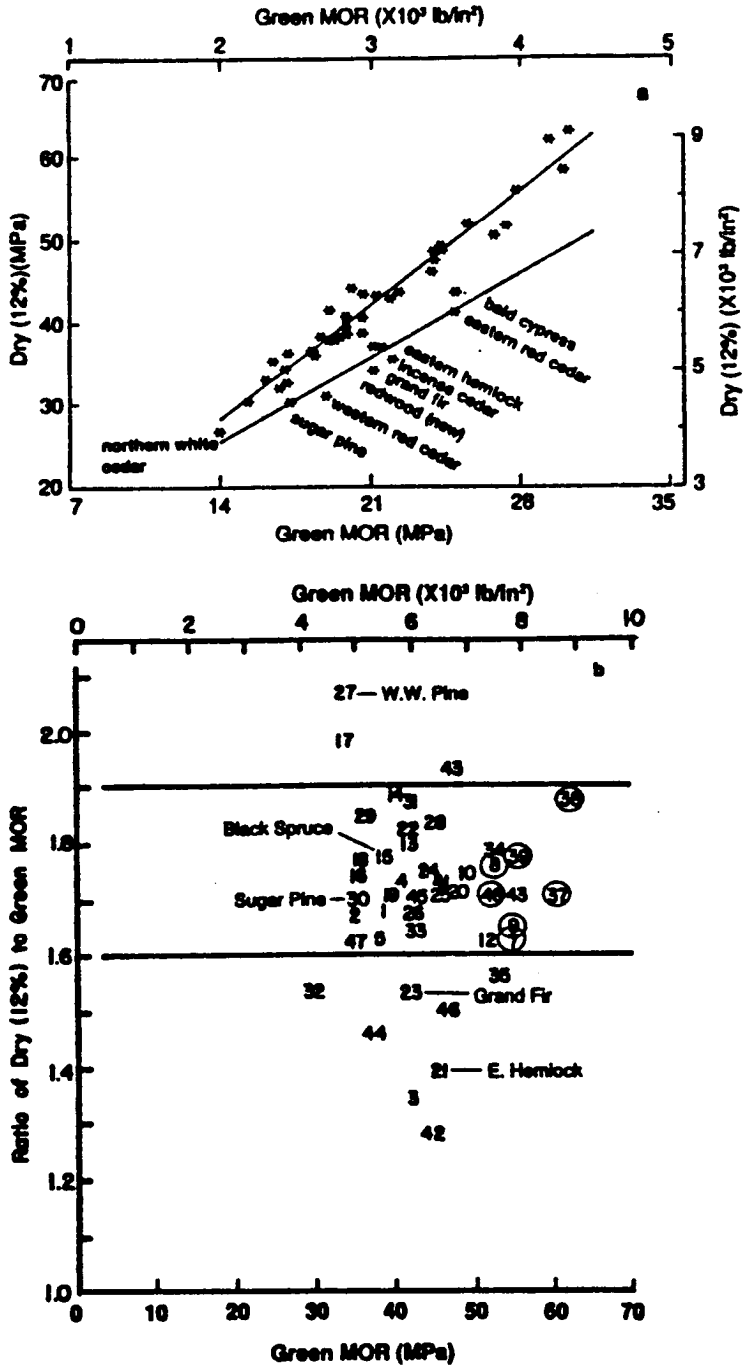

Figure 2 Effect of moisture content on the modulus of rupture of clear softwoods (5) (a); dry–green relationships for clear softwood species (b).

10% and 15% MC levels was carefully dried using a mild schedule in which the dry bulb reading did not exceed 49°C (120°F). The specimens were removed from the kiln when the mean MC was several percentage points above the target MC, and then the specimens were placed in appropriate equilibration chambers. Finally, the lumber was regraded and any change in grade was noted.

After equilibration of the lumber to the target MC, one piece at a time was removed from the conditioning chamber for testing. The actual dimensions of the specimens were recorded. The lumber was tested to failure in edgewise bending using third-point loading and a span-to-depth ratio of 17:1 (D 4761) (l). The grade-controlling defect was located within the test span and randomly located with respect to the direction of loading. Both

modulus of rupture (MOR) and MOE in the edgewise orientation were calculated for each piece of lumber. Load deflection curves were obtained for each piece. Ovendry MC and specific gravity of each specimen were determined from short segments cut from near the location of failure (D 4442, D 2395) (l).

RESULTS AND DISCUSSION

Effectiveness of sorting procedure

Each group of approximately 50 specimens was "matched" across the three MC groups for a given species and grade. Strength ratio and MOE were used as matching variables. Based on mean flatwise MOE and strength ratio, matching was effective (Table 1). Further, little overlap occurred in the range of MCS at time of test between the various groups. For eastern hemlock, three pieces in each of the green SS and green No. 2 groups had MCs <30%. In both cases, these pieces were higher in the MOR and MOE distributions and have little effect on the percentile levels shown in Figures 3 to 6.

Modulus of rupture

Percentile estimates for the MOR of species tested in this study are shown in Figures 3 and 4. For comparison, the equivalent data obtained in previous studies on Douglas-fir and Southern Pine are also shown (2,6). For illustrative purposes, lines have been drawn between percentile estimates.

Note that with Douglas-fir and Southern Pine, the data for the 2 by 4's were predominately of two types. In the first type, No. 2 grade lumber, the data below about 40 MPa (6,000 lb/in^2) (at 10% MC) tended to be less sensitive to change in MC and may reach a msximum value at about 15% MC. In the second type, SS and No. 2 lumber, having stress levels above about 55 MPa (8,000 lb/in^2) at 10% MC tend to increase linearly with decreasing MC from green to 10% MC. Similar trends can be seen for other grade-combinations of these two species in Figures 3 and 4 (5). However, note that elimination of the percentile estimates at 20% MC from the data collected in the previous studies increased the apparent linearity of the MC-MOR relationship as shown in Figures 3 and 4.

For the five additional species reported in this paper, western white pine and sugar pine tended to behave the same as did Douglas-fir and southern Pine (Fig. 3, 4). The upper strength levels of SS grades are admittedly not quite as linear as those of Douglas-fir and Southern Pine but the trends were similar for most of the strength levels.

Grand fir tended to exhibit a linear relationship with decreasing MC. The lines tended to "fan" with increasing stress level. This was also generally true with blade spruce. At the 41- to 55-MPa (6,000- to 8,000-lb/in^2) level at 10% MC, the percentage change in MOR per percentage change in MC was 3.3% from 10% to green. At about 28 MPa (4,000-lb/in^2) level, the change was about 2.5% per percentage change in MC (Fig. 3, 4).

As expected from the literature (5), eastern hemlock was somewhat insensitive to change in MC, at least below a stress level of about 28 MPa (4,000 lb/in^2). Select Structural grade exhibited a nonlinear but increasing trend in MOR with decreasing MC. The No. 2 grade was basically insensitive to change in MC (Fig. 3, 4).

Modulus of elasticity

Percentile estimates for the MOE of species tested are shown in Figures 5 and 6. For comparison, the equivalent data obtained in previous studies on Douglas-fir and Southern Pine are also shown (2,6).

At less than about 13,800 MPa (2.0 x10^6 lb/in^2) at 10% MC, the Douglas-fir and southern Pine MOE data generally increased in a linear fashion with decreasing MC. Little difference

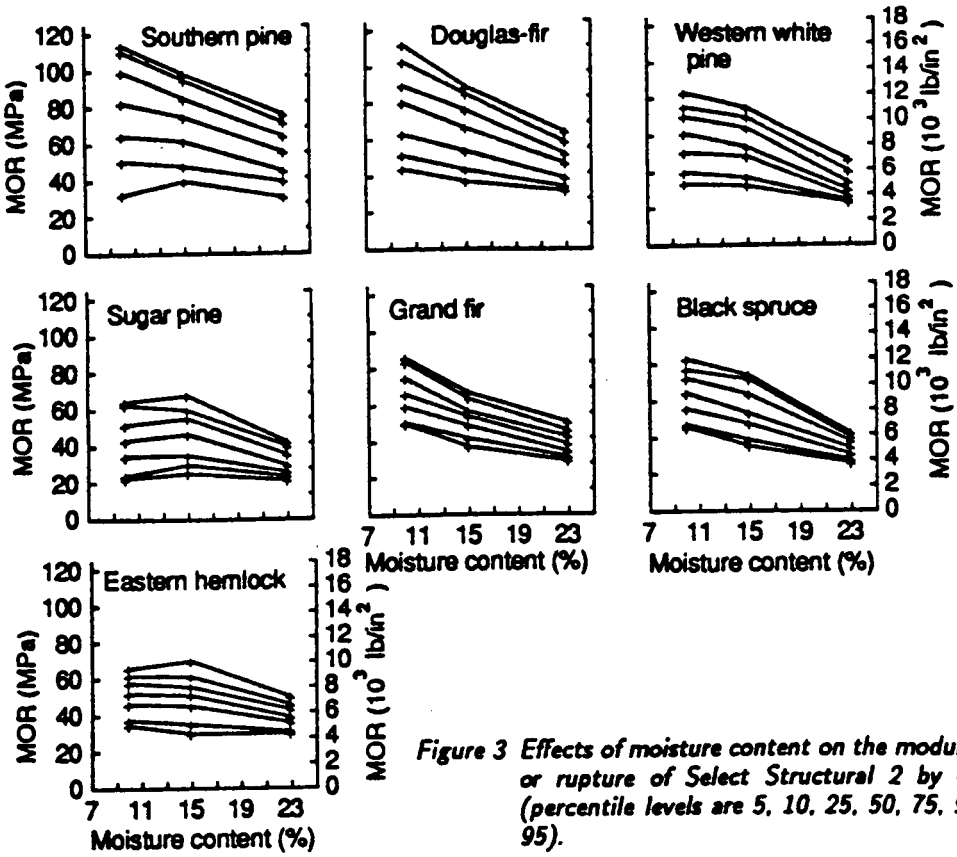

Figure 3 Effects of moisture content on the modulus or rupture of Select Structural 2 by 4's (percentile levels are 5, 10, 25, 50, 75, 90, 95).

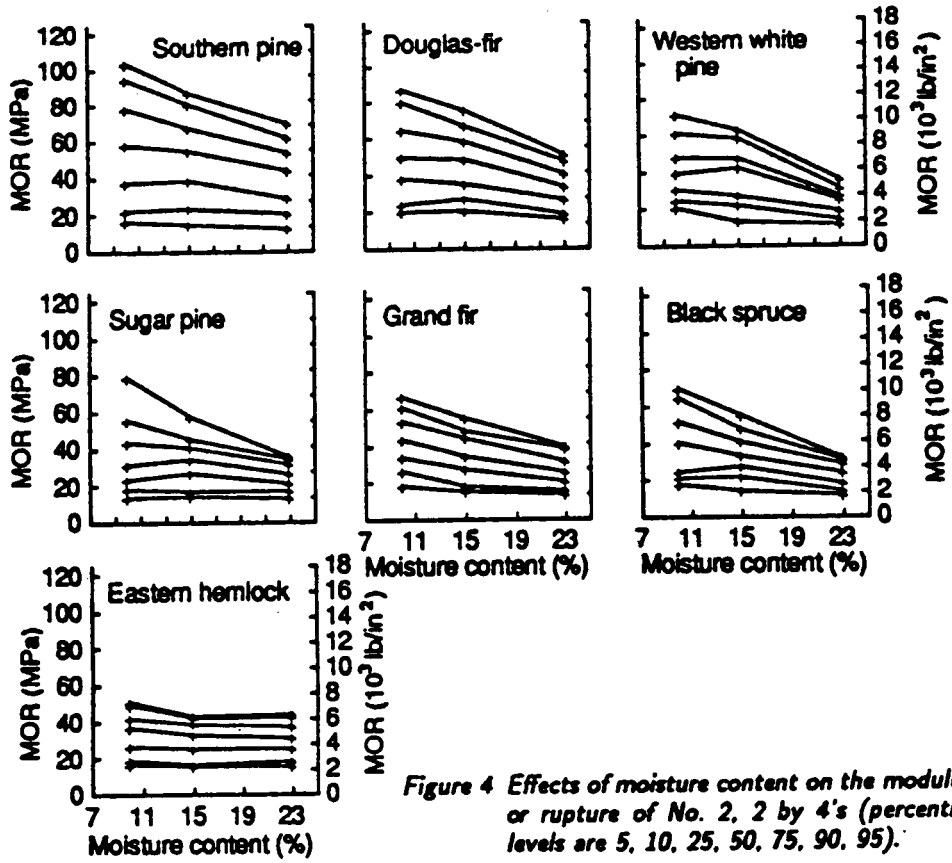

Figure 4 Effects of moisture content on the modulus or rupture of No. 2, 2 by 4's (percentile levels are 5, 10, 25, 50, 75, 90, 95).

Table 1. Effectiveness of sorting procedure across MC groups

Species	Grade[a]	Moisture content (%) Mean	Moisture content (%) Range	Sample size	Flatwise MOE (MPa ($\times 10^6$ lb/in^2))	Average strength ratio (%)
Sugar pine	SS	10	9–11	55	8,314 (1.206)	78
		15	14–19	54	8,307 (1.205)	79
		91	29–164	55	8,176 (1.186)	81
	No. 2	10	9–11	53	7,287 (1.057)	60
		15	13–16	54	7,315 (1.061)	60
		93	32–227	55	7,177 (1.041)	60
Western white pine	SS	11	9–13	53	10,493 (1.522)	83
		14	12–15	53	10,472 (1.519)	86
		55	29–127	53	10,479 (1.520)	84
	No. 2	11	9–12	50	8,914 (1.293)	57
		14	13–16	50	8,962 (1.300)	56
		65	31–171	50	8,804 (1.277)	54
Black spruce	SS	11	10–13	54	10,431 (1.513)	85
		15	14–17	54	10,334 (1.499)	87
		53	31–161	55	10,258 (1.488)	84
	No. 2	11	7–13	51	7,597 (1.102)	58
		16	14–17	54	7,680 (1.114)	62
		55	31–148	55	7,501 (1.088)	62
Grand fir	SS	11	11–12	52	11,113 (1.612)	88
		13	12–16	56	11,120 (1.613)	86
		106	31–189	57	11,161 (1.619)	87
	No. 2	10	9–12	55	8,328 (1.208)	59
		16	15–17	55	8,383 (1.216)	60
		100	37–199	54	8,342 (1.210)	57
Eastern hemlock	SS	13	11–13	55	8,873 (1.287)	92
		15	14–16	55	8,886 (1.289)	91
		57	22–115	55	8,886 (1.289)	92
	No. 2	12	11–13	54	7,218 (1.047)	69
		15	13–16	54	7,349 (1.066)	70
		62	21–192	55	7,315 (1.061)	67

[a]SS is Select Structural.

was noted between grades or between species. Some nonlinearity was indicated in the MC-MOE relationship greater than a MOE of about 13,800 MPa

For the five additional species reported in this paper, western white pine, sugar pine, and black spruce generally also exhibited a MC-MOE relationship that increased linearly with decreasing MC (Fig. 5, 6). For these three species and the Douglas-fir and Southern Pine, the average percentage change in MOE per percentage change in MC was 1.8 between 10% and 23% MC (assumed green value).

Grand h and eastern hemlock appeared to behave differently than the five species previously discussed. The MOE also increased with decreasing MC for grand fir. However,

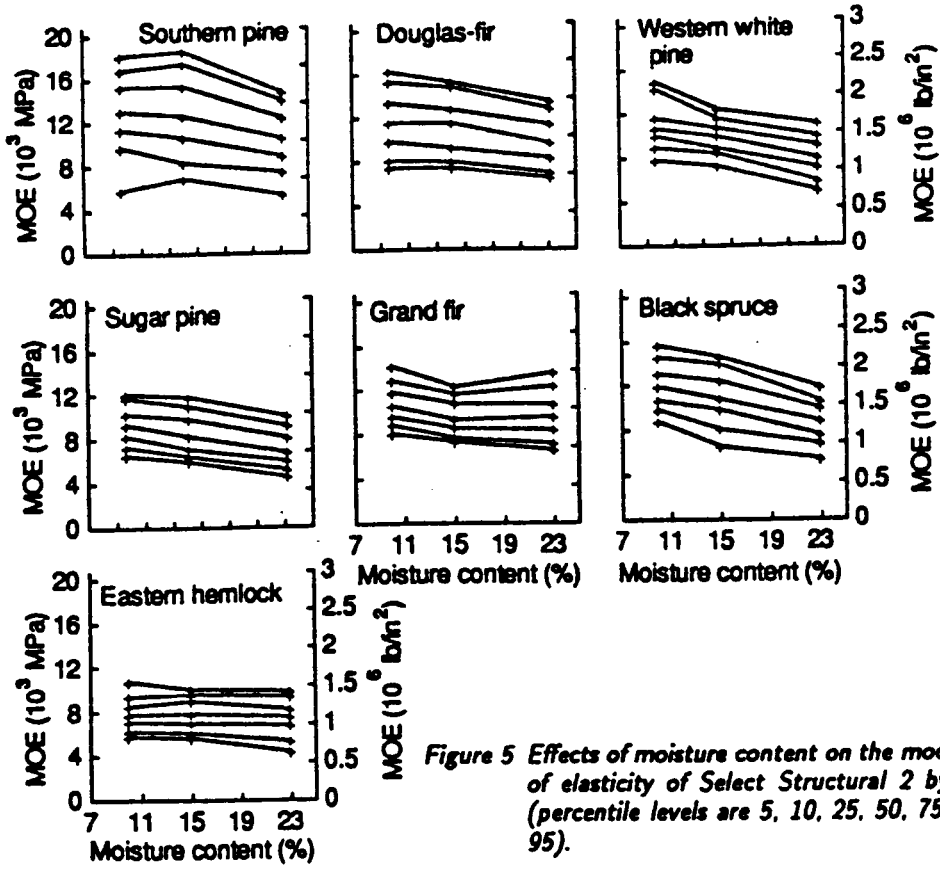

Figure 5 Effects of moisture content on the modulus of elasticity of Select Structural 2 by 4's (percentile levels are 5, 10, 25, 50, 75, 90, 95).

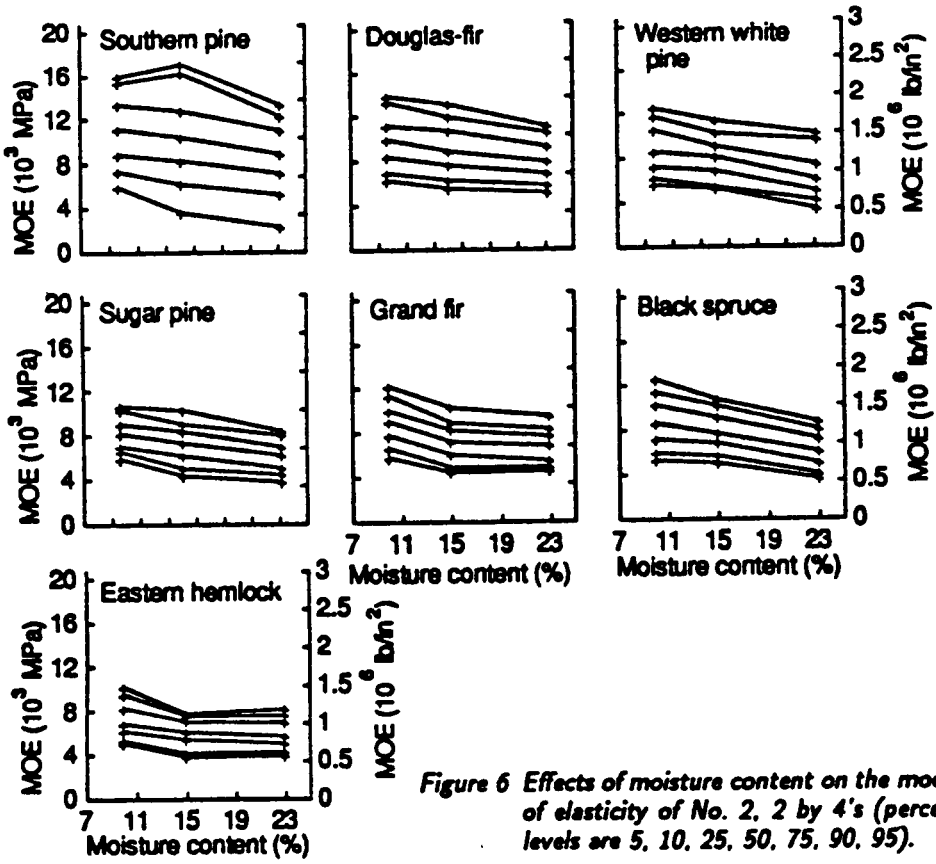

Figure 6 Effects of moisture content on the modulus of elasticity of No. 2, 2 by 4's (percentile levels are 5, 10, 25, 50, 75, 90, 95).

the relationship was not as linear as with the other five species. Select Structural grand fir was insensitive to change in MC between green and 15%. As was true with MOR, the MOE of eastern hemlock was less sensitive to change in MC than were the other species (Fig. 5, 6).

CONCLUSIONS

For the species evaluated, we conclude the following:

1. Douglas-fir, Southern Pine, wetstern white pine, and sugar pine exhibit similarities in change in MOR with change in MC. The weakest material is rather insensitive to change in MC and the strongest material increases linearly with change in MC. **The** MOR of lumber of intermediate quality may exhibit a maximum due at a MC level of about 15%.
2. The MOR of grand fir and black spruce for the weakest material tends to be insensitive to change in MC. However, at the intermediate and high strength levels, MOR tends to increase linearly with change in MC. Thus, straight lines representing the MC-MOR relationship tend to "fan" from the bottom to the top of MC-MOR plots.
3. The MC-MOE relationship is similar for Douglas-fir, Southern Pine, western white pine, sugar pine, and black spruce. The MC-MOE relationship tends to increase in a linear fashion without regard to species or grade. The percentage change in MOE with percentage change in MC is about 1.8 from 10% to green.
4. Both MOR and MOE of eastern hemlock are less sensitive to change in MC than the properties of the other discussed species.

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