MECHANICAL STRESS GRADING OF DAHURIAN LARCH STRUCTURAL LUMBER

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ABSTRACT

The objective of this study was to test a method under development for assigning allowable properties to foreign species graded by American Lumber Standard machine-stress-rated (MSR) rules. The method was tested on dahurian larch *(Larix dahurica)*, a major softwood species that grows in the Russian Far East and could be marketed in the United States. The relationship of tensile strength to bending strength for the test sample of dimension lumber was readily validated as similar to that for temperate softwoods from the United States and Canada. The results also showed a good relationship between bending strength and modulus of elasticity. Shear and compression perpendicular-to-grain strength values were weakly related to specific gravity, but barely met validation criteria. Edge-knot class and short-span flatwise modulus of elasticity were good sorting criteria for bending strength, as they are for MSR domestic lumber. Three published MSR grades representing a wide range of qualities were readily qualified. Tensile allowable stress was a limiting property. Achieving this property required the setting of boundaries that made the highest grade relatively rich in bending strength and stiffness and the lower grades relatively rich in tension. The sample could be sorted correctly into three selected grades nearly on the basis of edge-knot limitations alone. This study shows that this method can be used to machine stress rate dahurian larch into an array of existing domestic grades.

In the fall of 1990, when the seminal ideas for this study occurred, the outlook was bleak for approaching historical highs in timber harvest from public lands in the northwest United States. At that same time, dramatic changes were taking place in the USSR, and a number of Soviet delegations visiting the northwest United States expressed interest in using their abundant forests to foster trade.

The Oregon Legislature, searching for effective ways to help struggling sawmill-based local economies, seized on the Soviet interest and inquired about the feasibility of augmenting timber supplies in Oregon from Russian forests. However, the American Lumber Standard (ALS) system did not normally encompass softwood structural lumber from outside North America. In creating the Oregon budget for 1991-93, the Legislature identified "... the testing of Russian timber species in order to obtain . . . certification" under the ALS as a goal for the Oregon State University College of Forestry.

The ALS provides mechanisms for adopting standardized grading rules and associated design properties for domestic species (1); use of ALS-approved trademarks implies that both grading and properties are appropriate for the trademarked lumber. Proper grading is assured through an oversight process in sawmills; appropriate properties are assured through use of a complex set of material standards that enjoin, among other things, sampling requirements that lead to representative properties. Neither oversight nor representative sampling is easy to visualize for foreign sources of wood, where ALS jurisdiction may only be imposed when the wood reaches North America.

The problem, then, was to develop a scheme that could be reliably used to assign allowable properties to structural grades of foreign lumber as it is encountered in the United States. For orderly specification and marketing, it is not desirable to create new grades distinctly different from those already available in the ALS system. Therefore, we only considered adapting foreign species to existing ALS grades.

This problem is not entirely new. In the early 1970s, the Board of Review of the ALS committee approved a method called Testing Inference-Quality Control (TIQC) for dimension lumber made from species not grown in the United States or Canada (10). This method can be applied to lumber stress-graded by any technique. However, TIQC is cumbersome, and it has only been used once to obtain trademarks for lumber of a foreign species.

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TABLE 1. — Moisture content values at time of test.

Test mode	Average MC	Standard deviation	Sample size
	(%)		
Bending	15.6	1.09	215
Tension	15.1	0.93	226
Compression perpendicular to the grain	15.1	1.02	232

In mid-1993, Green and Shelley (12) offered a method for assigning properties to mechanically graded foreign species, which was accepted by the Board of Review. We were aware of these developing concepts and philosophies and we built our study around them, intending the study to represent the first major experience with the protocol approved by the Board of Review, providing a chance to both test and improve this protocol. The basic task was to show that a foreign species could be sorted by edge knot and modulus of elasticity in a way that would ensure desired allowable properties, and then to depend on the ongoing quality control under ALS scrutiny to ensure that the grading process worked on a continuing basis as sources of supply shifted from place to place.

We selected a single species for study, dahurian larch *(Larix dahurica),* because of its abundance and probable value for structural lumber. The general character of this sample of dahurian larch is described in detail in another paper (15). We designed and focused this study on machine-stress-rated (MSR) lumber because dahurian larch has a very large growth range and the MSR approach precludes any need to sample wood throughout that range. This paper describes how MSR dahurian larch fits into the ALS scheme, and it may provide a model for assessing other foreign species.

MATERIALS AND METHODS

SAMPLE SELECTION

The ALS protocol (12) calls for examining relationships between properties, particularly between tension strength and bending strength. We also planned to examine the relationship between compression parallel-to-grain strength and bending strength. The protocol recommends that these relationships be based on tests of 2 by 4 lumber.[1] To examine relationships between properties, it is desirable to force an approximately uniform distribution of the sample over the property range.

We used knot and slope-of-grain limitations from the current National Grading Rule for visual grades of Structural Light Framing (18, 19) to distribute the sample. Our goal was to obtain an equal number of pieces in each of the four grades at two locations. We did not achieve a uniform distribution of grades because of difficulty in finding pieces in the lower grades and difficulty in grading in the rough green condition (15). However, we were able to achieve a reasonable spread in the grade distribution. Additional details describing the sample, its selection, and its preparation are given in another paper (15).

The sample consisted of 696 12-foot (3.7-m) 2 by 4 pieces, approximately half from each of 2 sites 34 miles (55 km) apart. Upon arrival in the United States, the pieces were placed where they could be easily examined, and professional lumber inspectors were asked to classify each piece by largest edge knot as falling into a 1/2, 1/3, 1/4, or 1/6 knot class.[2] One-third of the sample was allocated by the method described in reference (15) for testing in bending, tension, and compression.

Specimens designated for compression parallel-to-grain testing were shipped to the Forest Products Laboratory in Madison, Wis. All other tests were conducted at Oregon State University in Corvallis, Oreg. Complications developed in the testing for compression parallel to the grain, and these problems have yet to be resolved. Since those tests are not a mandatory feature of the protocol, we have omitted them from this paper, pending resolution of the testing difficulties.

METHODS

The target moisture content (MC) for testing was 15 percent. Because all specimens were well above that MC level when received from Russia, additional drying was needed. The specimens were dried in a kiln, then stored for several months at 15 percent equilibrium MC. **Table 1** shows MC values measured at time of test.

The lowest flatwise modulus of elasticity (MOE) over a 4-foot (1.2-m) span was sought for each bending specimen, using a Metriguard static bending tester model 440.[3] This short span was presumed to be the weakest length of the piece. It became the central part (or nearly so) of a 5-foot (1.5-m) bending specimen that was cut from the 12-foot (3.7-m) length to achieve a span-depth ratio of 17:1. The remaining parts of each 2 by 4 were used to obtain shear and compression perpendicular-to-grain specimens for this study and to provide material for other studies.

All bending and tension tests were conducted in accordance with ASTM D 4761 (4). After testing, a small coupon was cut close to the failure zone in each specimen for determining MC at time of test and specific gravity (SG). MC was determined by ovendrying; SG was determined on the basis of volume by measurement (3).

Bending specimens were tested to failure edgewise with random selection of the tension side. Tension specimens were tested to failure full-length in a portable hydraulic machine (16) that provided an 8-foot (2.4-m) gauge length (overall length of 12 ft. (3.7 m)).

MOE was measured in several ways; here, MOE means the edgewise modulus over a 5-foot (1.5-m) span configured as in ASTM D 4761 (4). This modulus was predicted for all specimens, whether tested to failure in tension or bending, by the following procedure.

The modulus $(E_{dynamic})$ in full span, flatwise, dynamic vibration was measured on all specimens with a Metriguard E-computer, Model 3402.[4] In addition, for the bending specimens, the edgewise, 5-foot (1.5-m) span static modulus

[1] The term 2 by 4 refers to lumber with nominal dimensions of 2 by 4 inches (standard 38 by 89 mm).

[2] This is a criterion used in MSR grading rules in the western United States, The knot class represents the portion of the cross section of the piece occupied by the knot.

[3] Tradenames are for reader information only and do not represent endorsement by the U.S. Department of Agriculture of any product,

[4] Since different E-computer instruments have different built-in calibration constants, it is important to note that this copy of the E-computer has a calibration factor of 82.38,

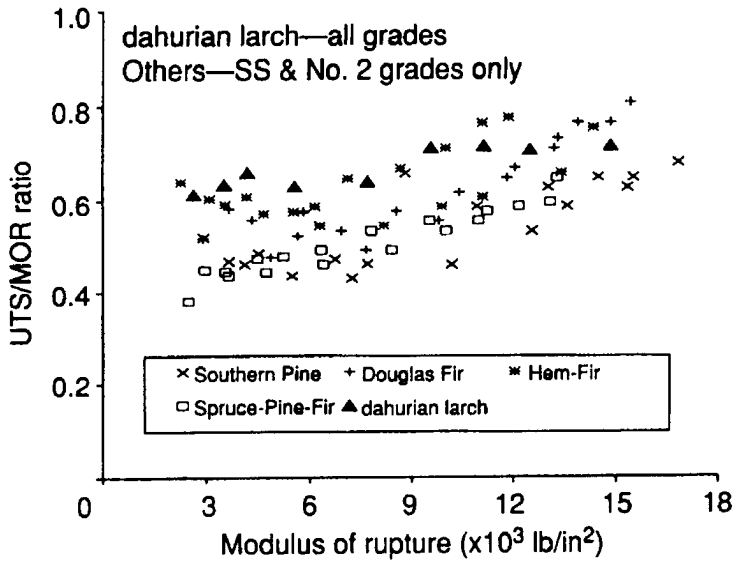

Figure 1. — Validation graph for ultimate tensile strength.

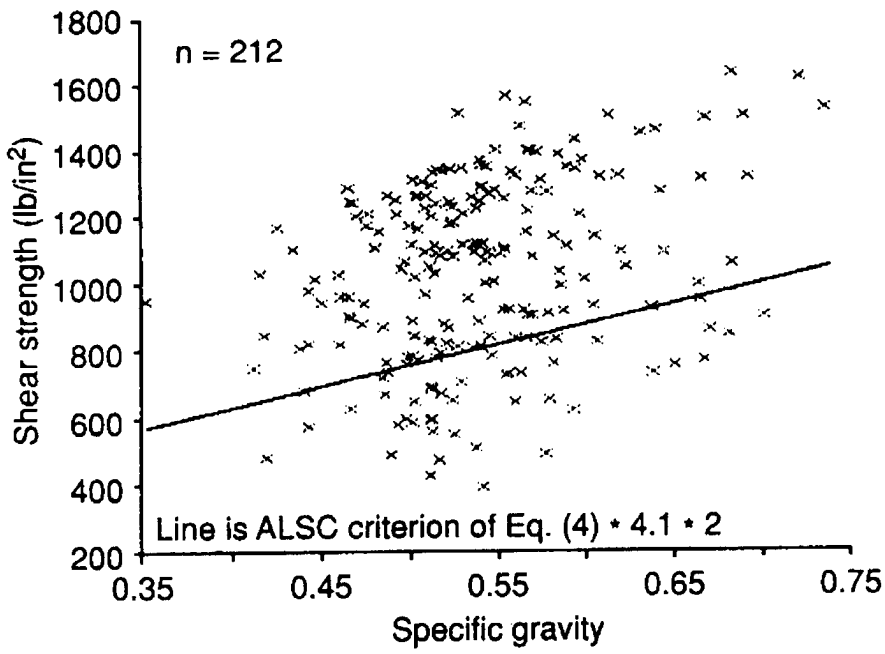

Figure 2. — Validation graph for shear strength.

(E_{edge}) was measured as part of the test to failure. From the bending specimens, a regression of edgewise modulus on flatwise dynamic modulus was obtained. The equation obtained was $E_{edge} = 0.927 (E_{dynamic}) - 0.045$; all measurements of modulus are in $\times 10^6$ psi (1 psi = 6.894 kPa.) This relationship had a coefficient of determination of 0.75. The predicted MOE for each test specimen is the value of E_{edge} obtained by entering the equation with the value of $E_{dynamic}$ measured on the specimen.

From each surplus 7-foot (2-m) length of bending specimen, a clear, straight-grained 10-inch (254-mm) length was selected to produce a shear and a compression perpendicular-to-grain specimen. Both specimens were made according to ASTM D 143 (2), except that one dimension was limited to the thickness of the piece of lumber, and there was no control over growth-ring orientation.

The shear specimen was 1.5 by 2 by 2.5 inches (38 by 51 by 64 mm), with a shear plane of 2 by 2 inches (51 by 51 mm). The compression specimen was 1.5 by 2 by 6 inches (38 by 51 by 152 mm), with the bearing area 2 by 2 inches (51 by 51 mm). The protocol (12) permits nonstandard specimens for these two tests.

The testing method for both shear and compression perpendicular to the grain followed ASTM D 143 (2). After the compression test, a short cross section was removed for determining MC, growth rate, percentage of summerwood, and SG. Results of these physical characteristics are given in reference (15).

In this paper, all mechanical properties were adjusted from tested MC to 15.0 percent MC using adjustments given in the ASTM D 1990 annex (6). SG was based on volume at 12 percent MC; the adjustment in the ASTM D 2395 (3) appendix was used. Average difference between sites was tested for all properties, and no site differences were found. Therefore, pooled data across sites are used here.

Results and discussion

Relationships between properties

The MSR protocol (12) for a foreign species requires that certain property relationships be demonstrably similar to those published for domestic species of the same type, in the case of dahurian larch, similar to those for domestic temperate softwoods. This process of comparing the foreign species with an understanding of domestic wood is called species validation. The protocol requires validation in the relationship between tensile strength and bending strength, between compression perpendicular to the grain (C_{perp})[5] and SG, and between shear strength and SG.

We developed sample distributions for tensile strength (UTS) and bending strength (MOR), then selected strength values at preselected frequency levels, using ASTM D 2915, section 4.5.4 (5), to form ratios of UTS/MOR. The ratios are

[5] Here, C_{perp} is taken to be the stress at 0.04-inch (1.02-mm) deflection, per ASTM D 245, section 6.2.4 (7).

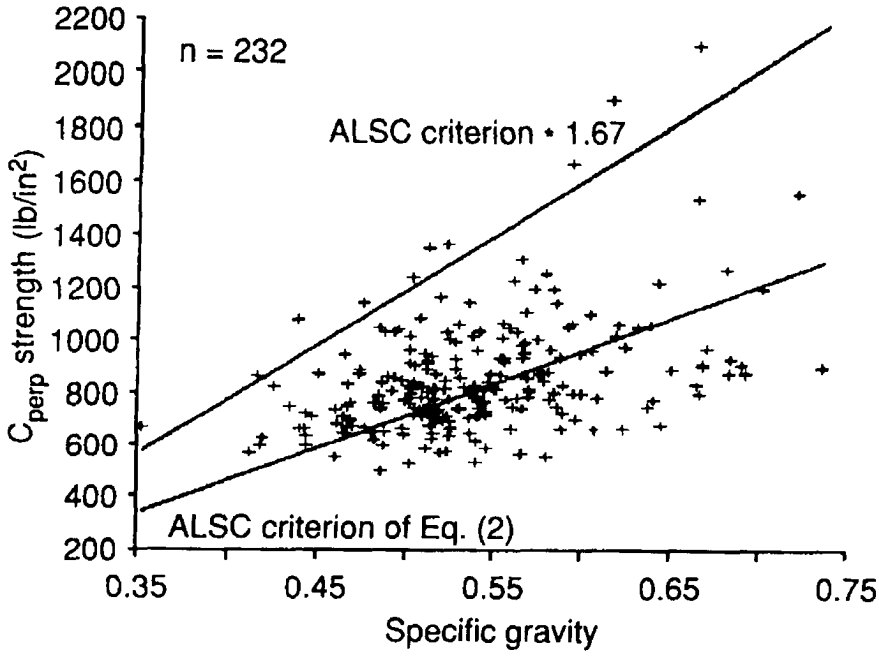

Figure 3. — Validation graph for compression strength perpendicular to the grain.

plotted in **Figure 1** and compared to domestic data of similar derivation taken from Green and Kretschmann (11). There is no test available to assess differences between the species **(Fig. 1).** However, it is apparent that dahurian larch behaves much like the domestic species plotted and has a UTS/MOR ratio generally higher than that of most of the other species.

Figures 2 and **3** show shear strength and C_{perp}, respectively, against SG.[6] The scatter plots show that neither property is very strongly related to SG. Simple linear regression yielded coefficients of determination of 0.10 and 0.17, respectively, both statistically significant. We know of no great amount of literature that would allow comparison of these relationships with domestic species. However, shear is reported in references (9) and (14) to have coefficients ranging from 0.06 to 0.69 for 13 domestic species. Reference (14) shows no coefficients of determination for C_{perp} versus SG, but states that "... the regression relationships . . . had [no] respectable r^2 values."

[6] Specific gravity was not measured on shear specimens but on C_{perp} specimens taken from an adjacent position in the lumber pieces, This introduced an additional source of variability.

Since direction of applied load relative to annual ring orientation was uncontrolled in the shear and C_{perp} specimens, we looked for any clue in the data that ring angle might be confounding these strength property/SG relationships. We found a distinct ring angle effect in C_{perp}, reported in reference (8). However, we found no significant relationship between shear strength and ring angle.

The specific requirement for validating the species in shear and C_{perp} in the ALS protocol is, "Regression equations fit to the data will then be compared to relationships assumed by the ALS committee (ALSC) for . . . F_{cp} density and F_v density." The ALSC-assumed relationships are those given in grading rulebooks. In reference (18), for example, the relationships are

$$F_v = 17.1 + (150.95 \text{ ö } SG) \quad [1]$$

$$F_{cperp} = (2498.9 \text{ ö } SG) - 537.7 \quad [2]$$

where:

F_v and F_{cperp} = allowable stresses
SG = specific gravity based on ovendry weight and volume at 12 percent MC

The protocol does not provide a mechanism for comparing the regression lines associated with the data in **Figures 2** and **3** with the ALSC-assumed relationships (Eqs. **[1]** and **[2]).** However, the ALSC-assumed relationships are in allowable stresses, not strengths. According to ASTM standards (e.g., reference (5), Table 9), F_v must be multiplied by 4.1 and F_{cperp} by 1.67 to convert them to the strengths from allowable stresses. In addition, for shear, the ordinates of the ALSC-assumed relationship should be doubled for the "split-beam" assumption. This assumption is derived from visual grading concepts (7), where it is noted that "... a bending member that is split completely through lengthwise will still hold one-half the shear load of an unsplit member" (section 4.2.3). In the development of published properties for both MSR and visual ALSC-approved grades, the rules-writing agencies have chosen to treat all grades as if they were split in half and have thus imposed a reduction factor of 2 in translating test results into an allowable shear stress.

The ALSC-assumed relationship for shear, with ordinates multiplied by 4.1 (the assumed reduction for duration of load and safety) and 2 (to account for the lengthwise split), is shown in **Figure 2.** By count, 47 of our 212 observations of shear strength fell below the line, amounting to 22 percent of the observations. Table 7 in reference (14) showed that, at most, only 3 percent of observations for several domestic species groups tallied below a line similarly derived. Thus, our data do not support the ALSC-assumed line. The protocol does not provide an alternative but presumably would permit calculating a 5 percent exclusion line, or something similar, from the data, to be substituted for the ALSC relationships as a validation. We did observe a high instance of shake in the larch. This could account for lower than expected shear strength.

For F_{cperp}, the ALSC-assumed relationship (solid line in **Fig. 3)** is clearly above most of the dahurian larch data (even recognizing that some plotted points may represent more than one specimen). We know of no published reference that shows the derivation of the line. However, according to reference (14), the line starts from green species average values from ASTM D 2555, increased by a dry/green ratio from the same standard. No doubt, those values were modified by the factor in ASTM D 245, which, according to section 6.2.1 of that standard, is a modification for the

most limiting ring position. Thus, the ALSC line is built from ASTM D 143 tests where the edges of the specimen correspond to radial and tangential ring orientations; the dahurian larch data are from tests in which ring angle was uncontrolled and in one sense incorporated the effect of ring angle experimentally. Therefore, if ordinates of the line in **Figure 3** are reduced by dividing by the 1.67 factor, the dotted line is obtained.

Since allowable F_{cperp} values for a species are based on average values, we expect about half the observations to fall on each side of the line used. If we do not multiply the ALSC criterion by the 1.67 factor that adjusts for random growth ring orientation,[7] we get a very credible line in **Figure 3.** Not to use the 1.67 factor seems reasonable because the ring orientation of specimens was randomized. Multiplying the criterion by 1.67 produces a line that is generally higher than that indicated by the data.

Although not required by the protocol, several other relationships between properties are seen in our data. Green and McDonald (13) point out that for MSR, "... knowing the relationship of MOE to MOR is not really necessary to qualify a grade." However, proof of such a relationship increases the comfort level that MSR will work; it also gives a first approximation of where grade boundaries might be set in the actual grading process, although quality control procedures are designed to fine-tune those boundaries as grading takes place.

Figure 4 shows MOR plotted against the lowest flatwise MOE over a 4-foot (1.2-m) span observed on each piece of lumber (approximately one grading criterion of MSR). The coefficient of determination relating the two is 0.45; that is, the lowest short-span flatwise MOE explains 43 percent of the variation in edgewise MOR. **Figure 5** is a plot of the same MOR against the edgewise MOE over a 5-foot (1.5-m) span. In this case, the coefficient improves to 0.60, no doubt an expression of the improvement when both properties are measured in the same orientation.

Edge-knot class is also a criterion for grading by MSR. Edge knots were classified on the full 12-foot (3.7-m) piece from which bending specimens were taken, but they were not classified on the 5-foot (1.5-m) specimens. **Figure 6** is a plot of average MOR against the strength ratio that corresponds to 1/2, 1/3, 1/4, and 1/6 knots as measured per ASTM D 245 (7). It is clear from our data that on the average, edge-knot size is a measure of MOR; that is, as edge-knot strength ratio increases, MOR also increases.

ESTIMATION OF ALLOWABLE PROPERTIES FOR GRADED LUMBER

For MSR, there is a given set of allowable properties that accompany existing MSR grades, shown in grading rulebooks (18, 19). To start the grading proc-

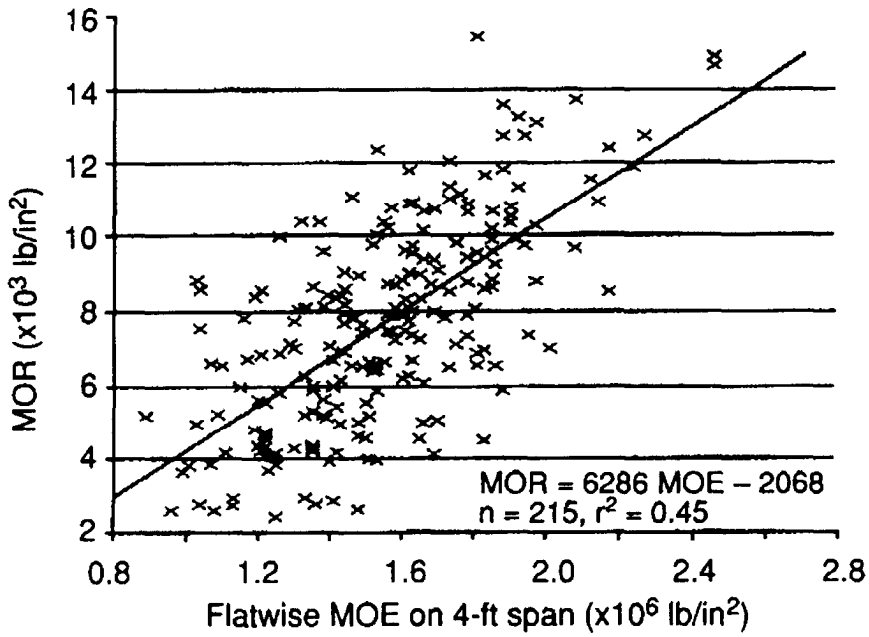

Figure 4. — Relation of bending strength to short-span MOE (1 ft. = 0.3048 m).

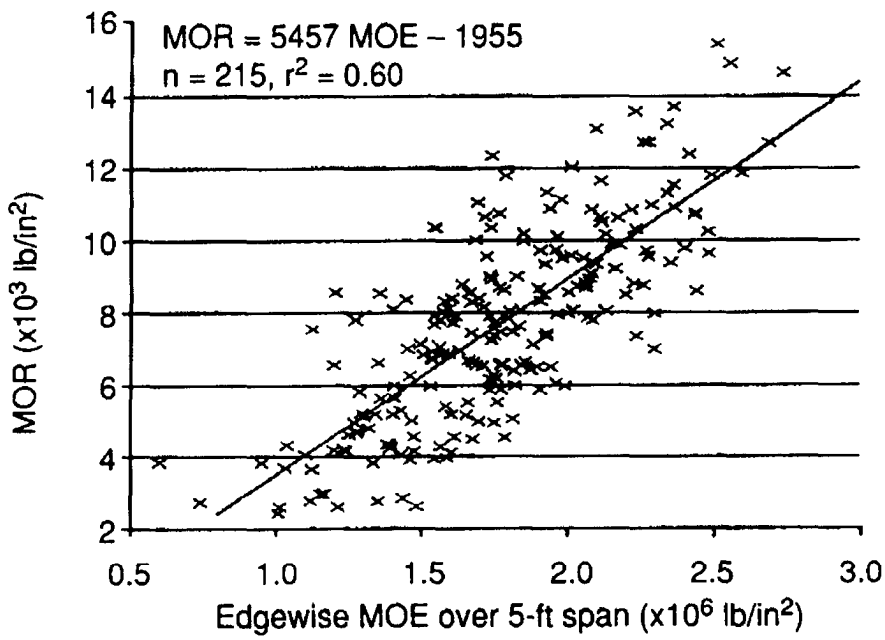

Figure 5. — Relation of bending strength to edgewise MOE.

7 For additional details about the effect of ring angle on compression stress perpendicular to the grain at a 0.04-inch (1.02-mm) deflection, see reference (9).

ess, the user decides which of those grades will be manufactured and sets up the grading machine and the quality control procedures to ensure that the lumber is sorted to those properties.

This approach is recognized in the ALS Board of Review protocol (12), which generally prescribes that "grade qualification will follow grading agency procedures approved by the Board." We followed those agency procedures (17,20) for three selected MSR grades. After we rejected 18 pieces with edge knots greater than 1/2 (thus not allowed in any MSR grade) and lost 5 other specimens as a result of various experimental problems, 441 pieces remained for the bending (215 pieces) and tension (226 pieces) tests. Thus, to get a reasonable size sample in any grade, only three grades were selected: 1.0E-900f, 1.2E-1200f, and 1.9E-2250f.

One of those grades had to be l.0E-900f because this is the only MSR grade that allows 1/2 edge knots and the sample had a substantial sample fraction with edge knots in that class. For a highest grade, the 1.9E-2250f grade was selected because that grade is in the quality range commonly accepted for trusses and other engineered uses. The 1.2E- 1200f grade was selected because it would most likely accommodate all the material that did not fall in either of the other two grades.

The agency procedures (17,20) will not be duplicated here. However, they establish the following decision rules for each grade:

1. The average edgewise MOE must equal or exceed the MOE assigned to the grade.

2. The 5th percentile nonparametric point estimate of edge bending MOE must equal or exceed 81.9 percent (one procedure uses 82%) of the MOE assigned to the grade.

3. The 5th percentile point estimate of MOR should equal or exceed 2.1 times the assigned allowable bending stress; similarly, in tension, 2.1 times the allowable tension stress.

4. The average SG should be high enough to ensure shear and C_{perp} allowable stresses assigned to the grade, when those stresses are predicted from Equations **[1]** and **[2].**

There is no agency procedure for establishing an allowable stress in compression parallel to the grain *(F_c).* However, the protocol (12) permits prediction of that property by an equation relating it to MOR.

Table 2 shows the highest set of allowable properties that can be justified for dahurian larch of the three grades, based on this sample and agency procedures. Bending, tension, and SG are obtained by iterative sorts of the data by edge knot and MOE; in each iteration, the first three conditions described here are examined. If any condition is violated, successively higher levels of MOE are chosen, which eliminates the least stiff pieces from the grade, until the condition is met. After several iterations, the minimum MOE for each grade is established in which all conditions are met in either bending or tension; that MOE is then used as a minimum level in examining the other property (tension or bending) to make certain that it too meets the conditions. When all conditions are finally met for both types of test, the pieces are established in each grade. The average SG for specimens in that grade is calculated, which permits calculation of F_v and F_{cperp} by the formula given in agency procedures; F_c is obtained by the formula in the protocol (12).

In the analyses of the dahurian larch data sorted into edge-knot classes, tensile strength in the 1.9E-2250f grade was the controlling property. That is, decision rule 3 dictated which pieces with 1/6 edge knots could remain in the grade, and this corresponded to a limiting MOE for that sort of 1.797×10^6 psi. For the other two grades, the pieces placed in the grade by edge-knot limitations plus those that

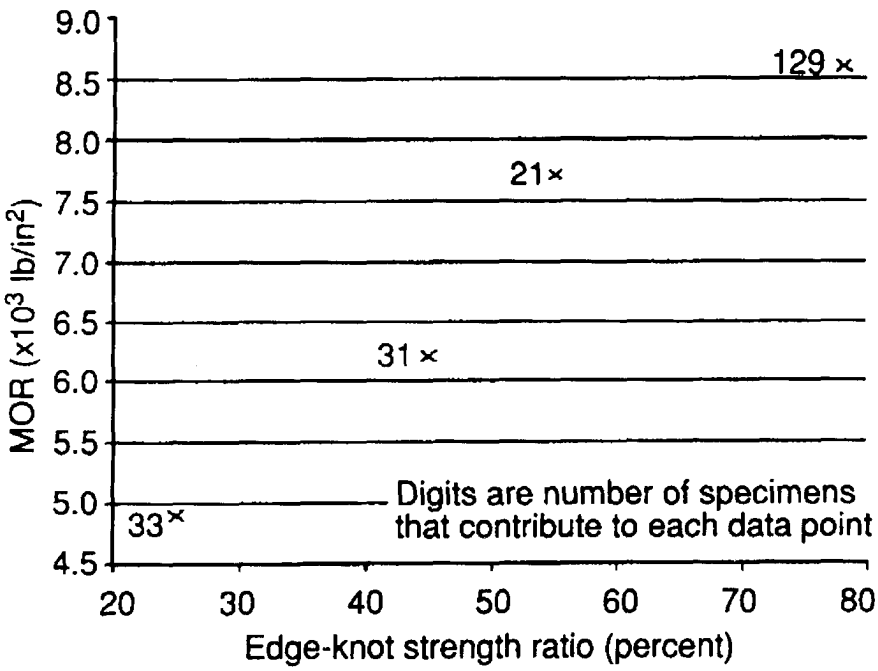

Figure 6. — Relation of bending strength to edge-knot strength ratio.

TABLE 2. — Allowable properties per agency procedures.

Property[a]	Grade		
	1.9E-2250f	1.2E-1200f	1.0E-900f
MOE ($\times 10^6$ psi)	2.1	1.6	1.5
F_b (psi)	2,400	1,900	1,200
F_t (psi)	1,800	1,100	775
F_c (psi)	1,925	1,400	1,050
F_v (psi)	100	95	95
F_{cperp} (psi)	875	775	740
Specific gravity	0.566	0.526	0.512

[a] 1 psi = 6.89 kPa.

did not fit the higher grade met all three decision rules. The lowest MOE in each of those sorts was as follows:

Grade	MOE
	($\times 10^6$ psi)
1.9E-2250f	1.797
1.2E-1200f	0.972
1.0E-900f	1.060

Using these limiting MOES with the bending data, all decision rules were satisfied for all three grades, without any further elimination of lower MOE pieces. One conclusion that can be drawn from this analysis is that edge-knot size alone is nearly sufficient to sort the pieces into the grades chosen, at least for these three well-spread grades.

The values in **Table 2** are most useful if they are compared with values for MSR grades as shown in ALSC-approved rulebooks. For each property and grade, the **Table 2** value should equal or exceed the corresponding one in the rulebook; the rulebook value is the one actually used to describe allowable properties for the lumber. For all three grades, values for MOE, F_b, F_t, and F_c in **Table 2** equal or exceed those given in references (18 **(Table 13,** p. 207)) and (19).

It is interesting to observe how much the experimental values for dahurian larch exceed the rulebook values. This introduces the concept of what we have come to call "property richness," which is the amount of a property that apparently cannot be used advantageously because of the restricted set of property tables in the rulebook. **Table 3** gives property richness values. There is no richness for F_c because it was derived by formula and exactly equals the rulebook values for all grades.

The value in **Table 3** for F_t richness in the 1.9E-2250f grade, within rounding rules, is near zero (actually 50 psi). This means that in following agency procedures, tension strength was the controlling condition. To achieve the tension property published for the grade, a sorting level of MOE had to be set that gave richness in the bending properties. For all other cases, there is richness in all of the **Table 3** properties. This implies that in this sample, edge-knot size alone as a sorting criterion produced richness in all properties.

Allowable properties in shear and compression perpendicular to the grain are not fixed for all species and each MSR grade in the grading rules (thus no richness parameter is given in **Table 3),** Rather, each species has its own allowable properties. In the previous section on validation, we discussed how the property-to-SG relations in agency procedures (the ALSC-assumed lines) do not fit the dahurian larch data unless 1) the split-in-half assumption is not made for shear, and 2) the larch compression perpendicular-to-grain data are assumed to inherently contain an adjustment for ring angle. Thus, under those assumptions, the allowable F_v and F_{cperp} in **Table 2** are exactly what they should be (no richness).

TABLE 3. — Property richness in three selected grades.

Property	Grade		
	1.9E-2250f	1.2E-1200f	1.0E-900f
MOE ($\times 10^6$ psi)	0.2	0.4	0.5
F_b (psi)	150	700	300
F_t (psi)	50	500	425

CONCLUSION

The MSR grading rules adopted in the American Lumber Standard system currently exceed 20 grades, not all of them produced and available in the marketplace. It is unlikely that any manufacturer would produce more than a few selected grades, and all manufacturers may not choose the same few. Those we selected show that dahurian larch would fit very well into the MSR grades and be as reliable as any domestic species graded in the same fashion. Because the principles (the relationships between properties) are similar for dahurian larch and for domestic species, we would have expected similar results had we chosen a different set of MSR grades to study.

It is interesting that edge-knot class alone had such a profound ability to sort these samples into classes that met nearly all of the agency decision rules. This suggests that edge knots and MOE, as dual grading criteria, may provide redundancy (could do almost as well with one or the other) as long as the current set of MSR grades is used. However, the richness in the **Table 3** data also suggests that some efficiencies could be achieved by defining some new grades that would be less rich, and to do that, the dual grading criteria might well be necessary. This is, of course, only one study of one species, and more species would need to be studied to determine if the richness phenomenon consistently occurs.

The agency procedures provide for a different way to develop allowable F_v *and* F_{cperp} than by using the ALSC-assumed relationships. This is done by following ASTM D 2915 and obtaining one value of each property for all grades of the species. Results obtained by using that method are shown below, compared with rulebook values for several species groups:

Species	*Fv*	*Fcperp*
Dahurian larch	140	570
Douglas-fir/larch	95	625
Hem-fir	75	405
Spruce-pine-fir	70	335

The F_v and F_{cperp} values for dahurian larch exceed that of all species except for the F_{cperp} for Douglas-fir/larch. As discussed previously, if the 1.67 factor for ring angle is omitted in the derivation of F_{cperp} for dahurian larch, arguing that the samples inherently compensated for ring angle, then the value for dahurian larch is 855 psi. Reference (8) shows that the average compression strength at the ring angle where it is lowest (about 45) is 750 psi. Nothing in the larch data suggests using a number lower than that.

The Green-Shelley protocol (12) provides the overriding direction for evaluating a foreign species for MSR grading, and in this example it worked well. What the study does not show (and was not designed to evaluate) is how much yield of mill-run lumber will fall into various grades. That question will be important to the profitability of anyone who intends to invest in bringing foreign lumber into U.S. markets. Within a species, mill-run lumber yield can be expected to change from one geographic location to another. However, our experience in finding it difficult to collect enough large-knotted pieces to achieve our target sample size suggests that the species should typically yield well in the higher grades, unless crook or other non-strength-related features cause it to downgrade.

This study demonstrated that the ALS-approved processes embodied in MSR grades in the rulebook, coupled with ALS-approved agency grade certification procedures, work quite well on dahurian larch.

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