Reviewed by:

Tom Zimmerman, Centre for
Frontier Engineering Research
200 Karl Clark Road
Edmonton, Alberta
T6N 1H2

MACHINE STRESS GRADING OF LUMBER AT LOW TEMPERATURES

1995

Prepared by:

Duane DeGeer, Centre for
Frontier Engineering Research
200 Karl Clark Road
Edmonton, Alberta
T6N 1H2

Lars Bach
Alberta Research Council
250 Karl Clark Road
Edmonton, Alberta
T6N 1E4

This is a joint publication of the Canadian Forest Service and
Land and Forest Service pursuant to the
Canada-Alberta Partnership Agreement in Forestry

A7014, XOD7092-127

DISCLAIMER

The study on which this report is based was funded in part under the Canada-Alberta Partnership Agreement in Forestry.

The views, conclusions and recommendations are those of the authors. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forest Service or Land and Forest Service.

Catalogue No.: Fo42-91/127-1995E
ISBN: 0-662-23404-9

Additional copies of this publication are available at no charge from:

Canadian Forest Service
Natural Resources Canada
Northern Forestry Centre
5320 - 122nd Street
Edmonton, Alberta
T6H 3S5
Telephone: (403) 435 - 7210

or

Land and Forest Service
Alberta Environmental Protection
10th Floor, 9920 - 108th Street
Edmonton, Alberta
T5K 2M4
Telephone: (403) 427 - 3551

* Note to readers:	metric equivalency comparisons are not consistent throughout the data in this report.

ABSTRACT

This report presents the results of a study aimed at obtaining quantitative data to determine the effects of temperature on the Modulus of Elasticity (MOE) and the Modulus of Rupture (MOR) for different grades of Alberta S-P-F 2"x4"x12' lumber samples. Approximately 500 specimens were Machine Stress Rated (MSR) to determine MOE at +20°C, -15°C and -30°C. In addition, 120 specimens were statically tested to destruction to determine actual MOE and MOR at the three test temperatures. The static testing was performed in accordance with NLGA Special Publications Standard 2 and ASTM Standard D 198.

As expected, the results indicate that there is an inversely proportional relationship between temperature and both MOE and MOR. That is, as the temperature is lowered, MOE and MOR increase. Relative to the test temperature, the static tests imply that MOE increases 0.13%/°C and MOR increases 0.34%/°C as the temperature decreases. The MSR tests resulted in an increase in MOE of 0.39%/°C as the temperature was lowered. It was also found that the change in MOE and MOR was greater when the temperature change resulted in a phase change of the moisture in the lumber samples. This implies that the moisture phase change is a significant factor in MOE and MOR changes with temperature.

ACKNOWLEDGEMENTS

Appreciation is expressed for the financial support for this work which was provided by the provincial and federal governments through the Canada-Alberta Partnership Agreement in Forestry. Thanks also to Mr. Bill Samborsky, at Millar Western Industries in Whitecourt, Alberta, for providing the wood samples. Special thanks for their contributions to Ted Szabo and Brian Karaim at Alberta Forestry, Lands and Wildlife.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Objectives

The objectives of this project are as follows:

- to determine the cold temperature effects on the relationship between flexural stiffness and flexural strength of structural sized lumber; and

- to determine low temperature calibration factors for Alberta lumber graded with BS 5268/SF-AF stress grading machines to provide reliable indications of actual strength.

1.2 Project Rationale

It has been rationalized that the development of better methods for determining the low temperature stiffness-strength relationship of structural sized lumber will result in:

- more reliable machine stress ratings, improving the safety and product marketability; and

- the possibility of avoiding a delay in proof testing lumber being Machine Stress Rated (MSR) at low temperatures by changing the requirement that it be heated prior to testing, reducing the cost and increasing the effectiveness of the quality assurance feedback system.

1.3 Work Plan

The following tasks were completed to fulfill the objectives stated above:

- low temperature testing of approximately 500 pieces of Alberta S-P-F 2"x4"x12' lumber with a commercial MSR machine (Techmach SG-AF). Low temperatures were accommodated by placing the lumber specimens in a large temperature-controlled laboratory; and

- lumber sample testing according to the procedures summarized in NLGA Special Publications Standard 2[1] and ASTM Standard D198[2] to determine the actual Modulus of Elasticity (MOE) and Modulus of Rupture (MOR).

Work included:

- project initiation (planning, test set-up, specimen preparation);
- room temperature tests at +20°C;
- cold temperature tests at -15°C;
- cold temperature tests at -30°C; and
- data synthesis and reporting.

1.4 Project Collaboration

This project was carried out as a co-operative effort between the Centre for Frontier Engineering Research (C-FER) and the Wood Products Engineering Section of the Alberta Research Council (ARC). Project management responsibilities were provided by C-FER; ARC was retained to provide services as subcontractor. Both organizations contributed to the major technical tasks of the project.

2.0 TEST PROCEDURES

A total of 520 pieces of Alberta S-P-F 2"x4"x12' lumber were obtained for testing from Millar Western Industries in Whitecourt, Alberta. Table 2.1 summarizes the test pieces. The number of pieces tested at the different temperatures are shown in Table 2.2.

Testing was performed in three phases corresponding to each of the three test temperatures. For each phase, static testing initiated shortly after commencement of the MSR testing. MSR testing was performed in about a day for each phase, with static testing taking about two days to complete.

Table 2.1. Summary of test pieces.

Grade Designation	No. of Pieces	Nominal Dimensions	Moisture Content
NLGA SPS2 MSR Grade 2100f	130	2" x 4" x 12'	Kiln Dried (<19%)
NLGA SPS2 MSR Grade 1650f	130	2" x 4" x 12'	Kiln Dried (<19%)
Millar Grade "J" (No. 1 equivalent)	130	2" x 4" x 12'	Kiln Dried (<19%)
Standard and Better	130	2" x 4" x 12'	Kiln Dried (<19%)

Table 2.2. Samples tested at different temperatures.

Test Temperature	No. of Pieces (MSR)				No. of Pieces Proof Tested to Failure			
	2100f	1650f	"J"	Std&Btr	2100f	1650f	"J"	Std&Btr
+20°C	130	130	130	130	10	10	10	10
-15°C	120	120	120	120	10	10	10	10
-30°C	110	110	110	110	10	10	10	10

For each of the test temperatures, the lumber was allowed to thermally equilibrate with the environment for a minimum of two days. Individual pieces were separated with spacer boards to maximize the actual lumber cooling rate, reducing the time required to achieve equilibrium. Temperature monitoring was performed using thermocouple probes inserted into holes drilled into random lumber pieces. Temperature measurements were taken at intervals (every few hours on average) and testing commenced once the lumber temperature matched the cold chamber temperature for two or more readings.

MSR machine operation problems at the low temperatures resulted in the decision to perform the MSR testing immediately outside the cold chamber area with the specimens transferred in and out of the cold chamber. The temperature of the lumber specimens was controlled inside the cold chamber. One at a time, the lumber specimens were taken from the cold chamber to the MSR machine for testing, then taken back into the cold chamber. The total time for MSR testing of an individual sample was about 30 seconds. Static testing was subsequently performed on the specimen in the cold chamber some time later.

2.1 Static Proof Tests

At each temperature, forty specimens (ten from each test grade) were statically tested on edge to determine MOE and MOR. All aspects of the static testing conformed to ASTM Standard D198 and NLGA Special Publications Standard 2. Figure 2.1 illustrates the test set-up.

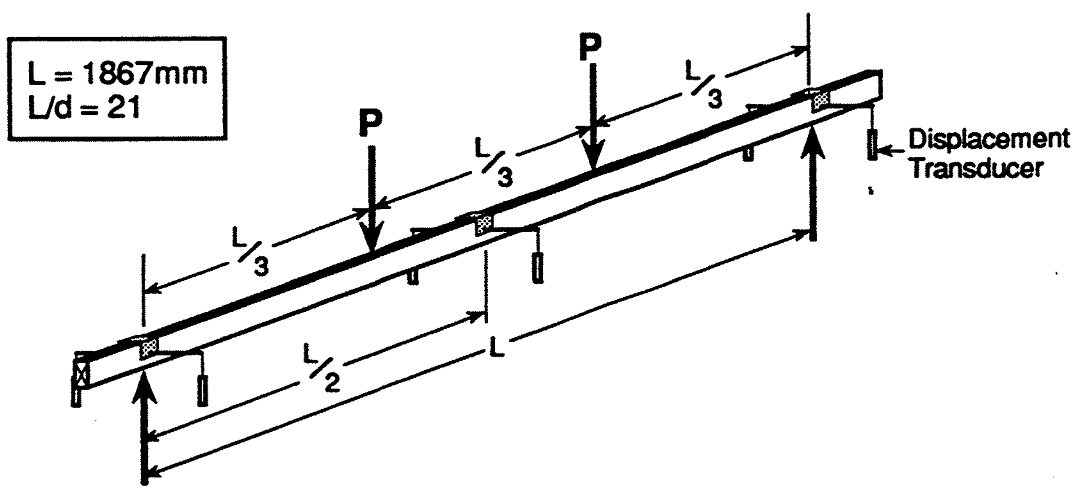


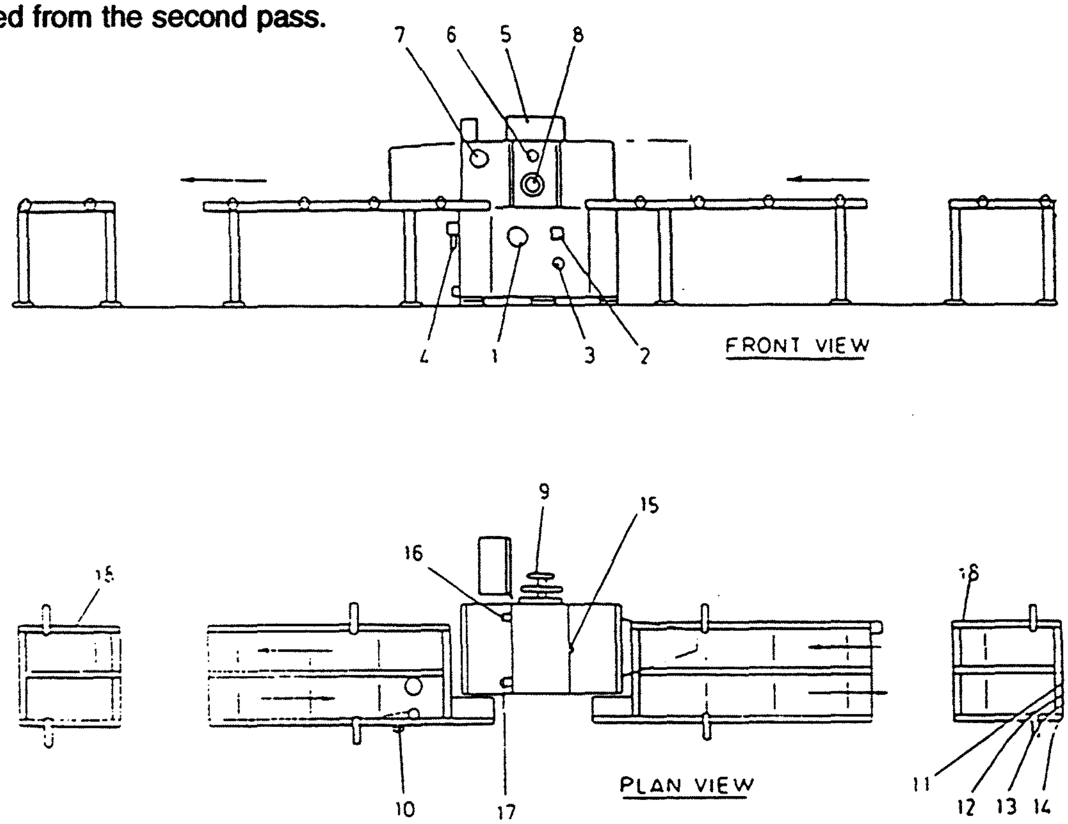
Figure 2.1. Static test set-up.

As Figure 2.1 shows, each specimen was loaded at the third points of the span. The loads P were applied using hydraulic actuators connected to a pump in parallel so loading was applied equally to each load point. Six displacement transducers were used to measure displacements at each of the reaction points and at the centre of the span. True midspan displacement was determined by subtracting the small displacements at the reaction points from the centre span measurements. As outlined in ASTM D198, loading was applied at a rate so as to achieve failure within 6 to 20 minutes. On average, each specimen failed after about 6 to 7 minutes of testing.

2.2 Machine Stress Rating (MSR) Tests

The machine stiffness rating tests were conducted with a commercial Stress Grading Machine manufactured by Techmach Ltd. (model no. SG-AF100, as shown in Figure 2.2). This type of machine is used in the United Kingdom to officially machine stress grade lumber according to the British Standards BS4978/BS5268.

The Techmach Stress Grading Machine operates using a single pass at a time. A single timber specimen is fed into the MSR machine twice to measure stiffness on both sides of the specimen (bending about the weak axis; i.e. on the flat side). While travelling through the machine, the timber is subjected to a pre-set deflection, the value of which depends on the size and species of the timber to be graded (for the tests described herein, the deflection was set at approximately 7.4 mm). The load that the timber specimen exerts on the load roller is measured by a computer. During the first pass, the load readings are taken every 100 mm, and are paired with the readings obtained from the second pass.



1. Main Electrical Isolator
2. Drive Motor Start/Stop Push Button
3. Drive Motor Lamp
4. Air Shut-Off Valve
5. Computer
6. Pinch Air Pressure Regulator
7. Pinch Air Pressure Gauge
8. Pinch Opening Adjusting Handwheel
9. Deflection Adjusting Handwheel
10. Return Roll Pinch Adjustment
11. Visual Reject Button
12. Visual Grade 1 Button
13. Manual System Reset
14. Emergency Stop
15. 1st Pass Lamp
16. Grade 2 Lamp
17. Grade 1 Lamp
18. Conveyor End Section

Figure 2.2. Techmach Stress Grading Machine (model no. SG-AF100).

In this project, the stiffness readings for all specimens tested were stored in the computer. The readings, obtained at each discrete point on the timber specimen for passes one and two, were averaged and stored as well. Analysis of the influence of temperature on stiffness was performed by comparing the MOE readings from the same location of each specimen at the three different test temperatures.

2.3 Other Measurements

2.3.1 Moisture Content

The moisture content was determined for each of the lumber samples tested to destruction in flexure. A representative sample was cut from each board (immediately after static testing to failure) and wrapped in a moisture-proof foil. The specimen was initially weighed, dried for 72 hours at approximately 105°C, then weighed again. The moisture content was calculated as the weight loss of the wood sample relative to its oven dry weight. The average values of the measured moisture content are presented in Chapter 3.

2.3.2 Lumber Dimensions

The width and height of each statically tested lumber specimen was measured. For these samples, the average cross section dimensions were 38.3 mm x 89.0 mm, with a coefficient of variation (COV) for each of the measurements not greater than 1%.

3.0 TEST RESULTS

This section presents the overall results of the static and MSR testing. Detailed test data can be found in a separate document[3].

3.1 Static Tests

Table 3.1 summarizes the static MOE and MOR results (MC = moisture content).

The COV for the MOR results is somewhat higher than those for the MOE tests. This can be primarily attributed to the increased sensitivity of MOR to variations in the specimens, such as knots (size and location) and grain orientation.

Figure 3.1 illustrates the relationship between temperature and MOE.

As expected, the previously machine rated grades 2100f and 1650f show a consistent trend of increase in MOE with a decrease in temperature. However, because the "J" grade group and the Standard and Better group consist of samples with a potentially larger stiffness range, the relationship between stiffness with temperature are less obvious.

The trends between MOR and temperature are shown in Figure 3.2.

Once again, the 2100f and 1650f grades show a reasonably consistent increase in MOR with temperature, and those for the "J" grade group and the Standard and Better group are not well defined.

The relationship between MOR and MOE is plotted in Figure 3.3. This figure shows the actual data points as well as the best fit line through the data for each test temperature. Also shown is the slope of the best fit line and correlation coefficient for each test temperature, indicating the correlation between the best fit line and the test data. When r = 1, the correlation is perfect, and when r = 0, there is no correlation.

Further assessments and graphical comparisons of the static test results to the MSR test results can be found in Section 3.3.

Table 3.1. Results of the static testing.

	+20°C			-15°C			-30°C		
Grade	MC (%)	MOE (GPa)	COV (%)	MC (%)	MOE (GPa)	COV (%)	MC (%)	MOE (GPa)	COV (%)
2100f	17.3	12.1	12	17.6	12.7	10	18.8	12.8	11
1650f	17.2	11.1	12	14.7	11.8	11	14.3	12.0	11
"J"	15.9	11.8	16	14.9	11.1	16	15.5	13.0	19
Std&Btr	15.3	11.8	16	14.5	11.2	13	15.6	12.2	16

	+20°C			-15°C			-30°C		
Grade	MC (%)	MOR (MPa)	COV (%)	MC (%)	MOR (MPa)	COV (%)	MC (%)	MOR (MPa)	COV (%)
2100f	17.3	50.8	15	17.6	62.4	19	18.8	59.0	25
1650f	17.2	40.2	12	14.7	53.7	21	14.3	56.5	21
"J"	15.9	50.3	23	14.9	44.2	39	15.5	61.7	38
Std&Btr	15.3	49.8	28	14.5	54.4	28	15.6	52.8	29

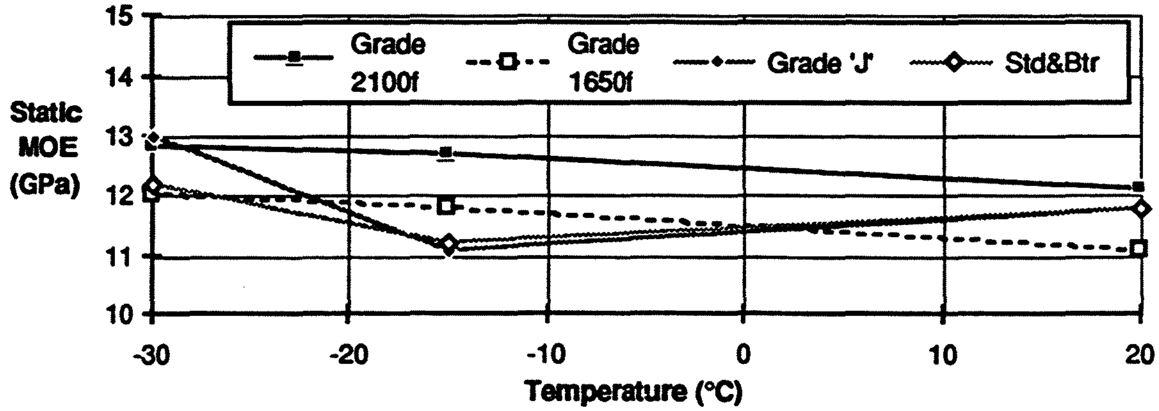


Figure 3.1. Static MOE vs. temperature.

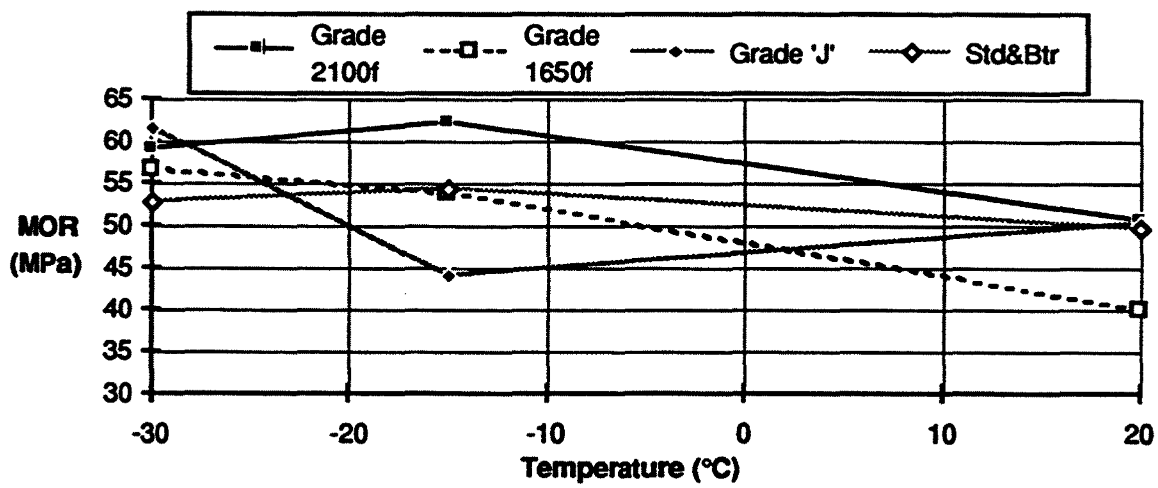


Figure 3.2. Static MOR vs. temperature.

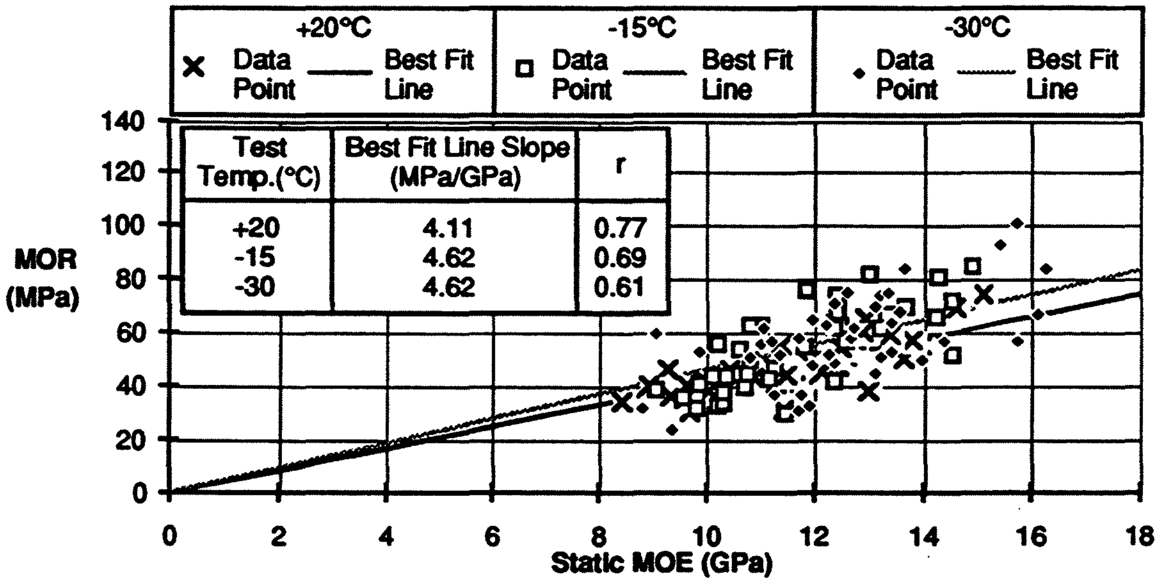


Figure 3.3. Static MOR vs. static MOE.

3.2 MSR Tests

The stiffness measurements of the boards on flat by the Techmach MSR machine are summarized in Table 3.2.

Figure 3.4 illustrates the relative cumulative frequency of MSR MOE data for each of the four grades tested at +20°C.

As expected, the cumulative frequency curves for the lumber grades 1650f and 2100f show a relatively consistent trend (due to their previous stiffness grading), and the spread for the "J" and Standard and Better grades is quite wide.

Figures 3.5, 3.6, 3.7, and 3.8 summarize the influence of temperature on MOE for each of the four grades. As can be seen in these figures, a large increase in MOE is observed for the temperature change from +20°C to -15°C, while a much smaller change occurs for the temperature change from -15°C to -30°C.

Figure 3.9 further illustrates the effect of temperature on the mean MOE values.

Table 3.2. Results of the MSR testing.

Grade	+20°C			-15°C			-30°C		
	MC (%)	MOE (GPa)	COV (%)	MC (%)	MOE (GPa)	COV (%)	MC (%)	MOE (GPa)	COV (%)
2100f	17.3	11.2	7	17.6	13.3	7	18.8	13.7	7
1650f	17.2	9.7	10	14.7	11.5	11	14.3	11.9	11
"J"	15.9	10.3	17	14.9	12.1	17	15.5	12.7	13
Std&Btr	15.3	10.4	13	14.5	12.0	14	15.6	12.5	13

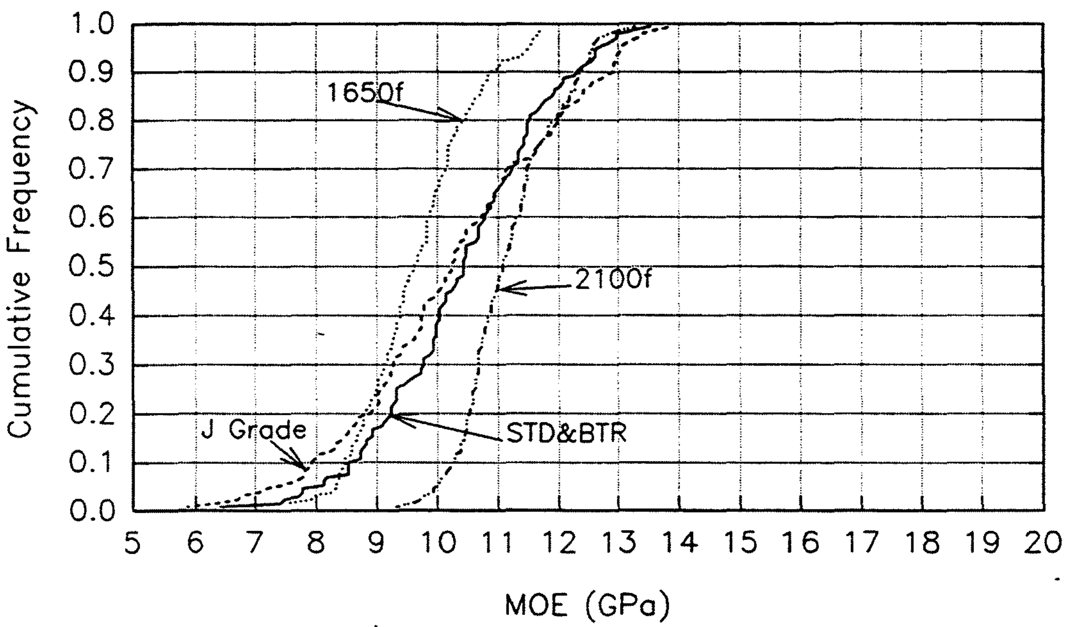


Figure 3.4. MSR results at +20°C.

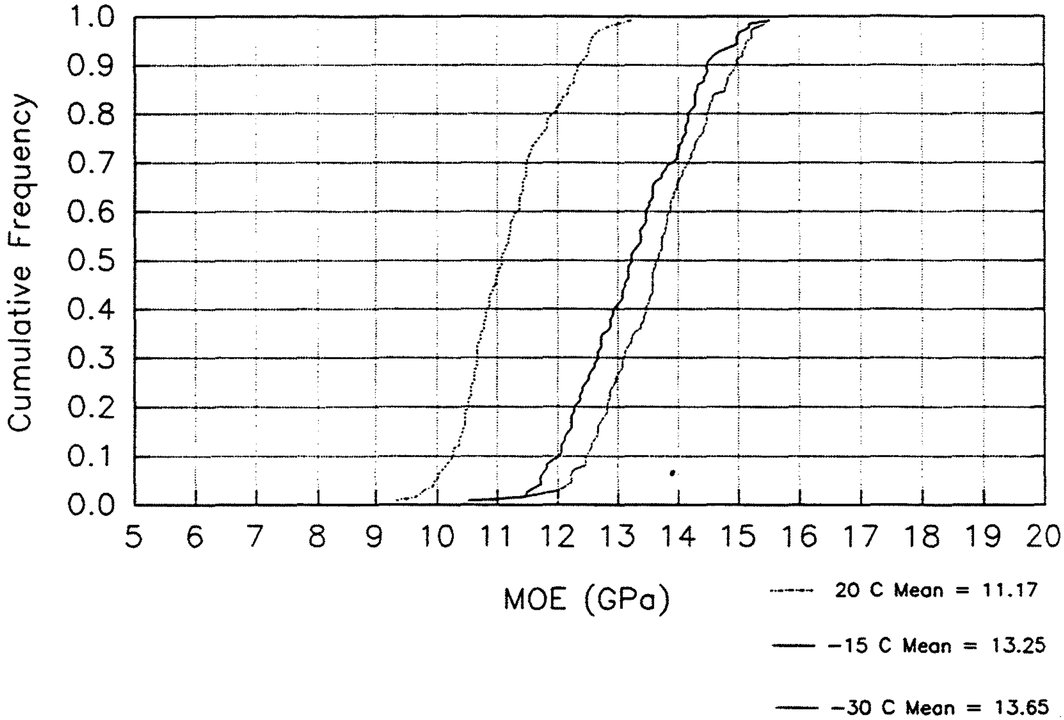


Figure 3.5. MSR results for grade 2100f.

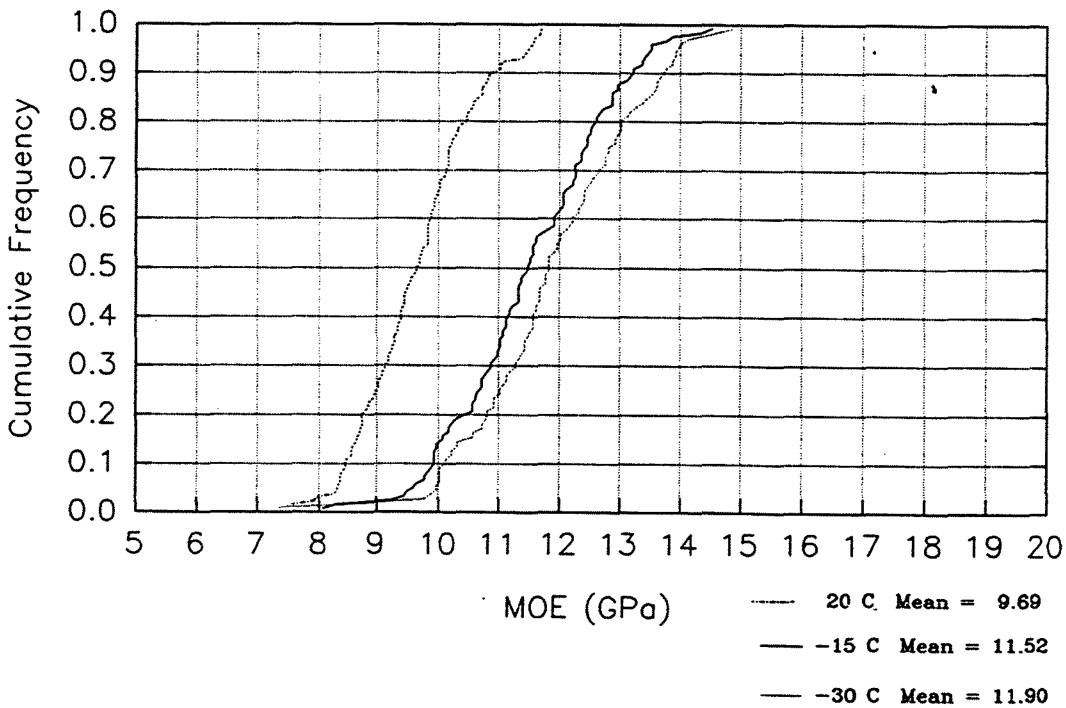


Figure 3.6. MSR results for grade 1650f.

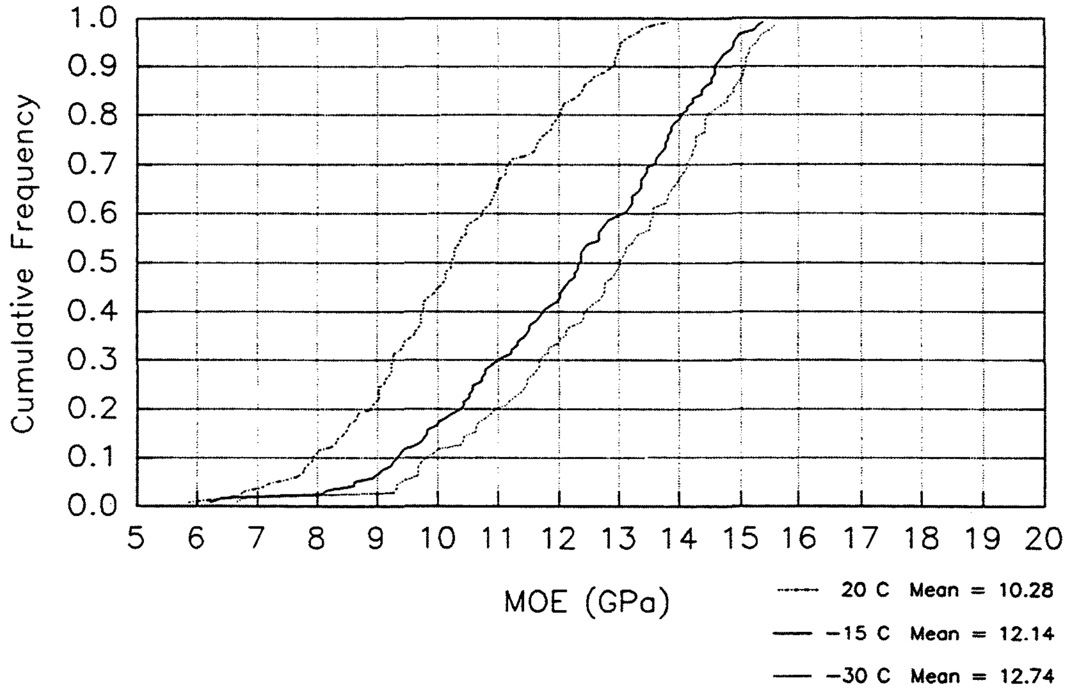


Figure 3.7. MSR results for grade "J".

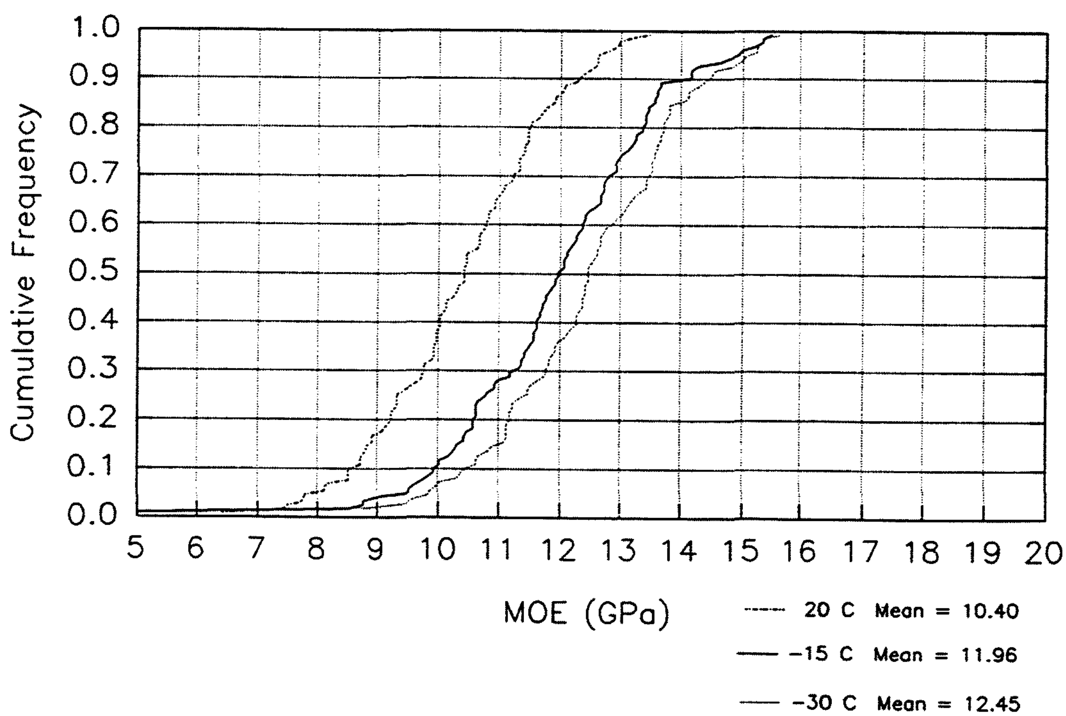


Figure 3.8. MSR results for grade Standard and Better.

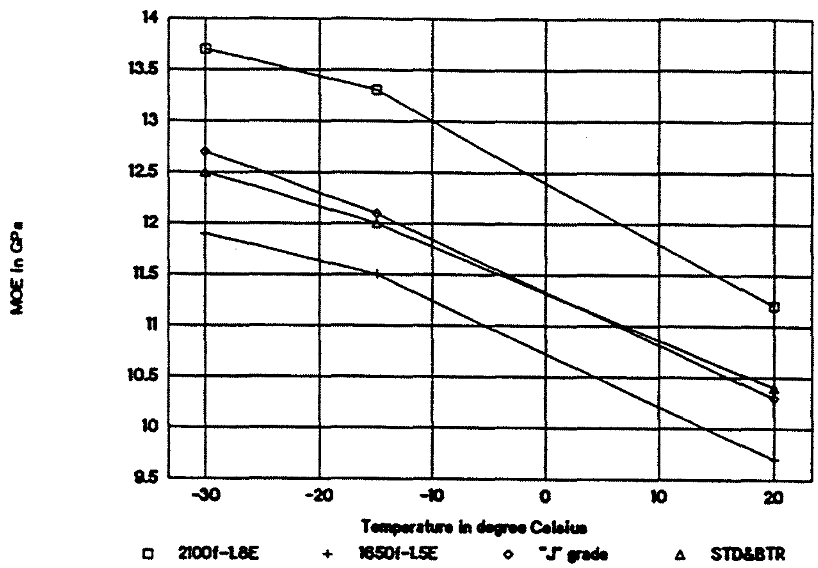


Figure 3.9. MSR MOE vs. temperature.

3.3 Discussion and Comparison of Test Results

Machine stress rating of lumber with the Techmach machine (as well as other machines, like the Computermatic and CLT) rely on a "non-destructive flexure" determination of the MOE (measured on the flat side of the 2"x4" specimen). Subsequent MSR grade classification is determined by using known correlations between the MSR machine readings and static MOR and MOE (on edge) determined at room temperature. In accordance with the current understanding of the effects of temperature on MOE and MOR, the series of tests described in this report show that when the MSR readings are used to estimate static MOR and MOE, a correction should be made for the temperature of the lumber.

The results of the static and MSR stiffness testing indicate somewhat different trends with temperature. As indicated by Lum[4], the equation to correct stiffness values at cold temperatures to +20°C stiffness values can take the form:

$$MOE_{+20^\circ C} = MOE_T[1 + K_T(20^\circ C - T)]$$

where: T = temperature in °C

The above equation can be rearranged to take the form:

$$K_T = \frac{MOE_{+20^\circ C} - MOE_T}{MOE_T(20^\circ C - T)}$$

Using the results obtained in this study, the following linear approximations can be made to determine the change in mean MOE with temperature:

$K_T = -0.0013/^\circ C$ (Static Tests)

$K_T = -0.0039/^\circ C$ (MSR Tests)

The preceding equations indicate that there is some difference between the MSR and static MOE relationship with temperature. The study described by Lum[4] suggests that K_T can vary considerably, but that a value of around -0.0025/°C can be expected for moisture contents within the range of values measured in this test program (14 to 19%). The primary difference between the MSR and static K_T factors can be attributed to the large difference in room temperature MOE values, where the MSR values were, on average, about 12% less than those of the static tests.

The same correction approach can be made for the MOR results. By replacing MOE with MOR in the K_T equation on the preceding page, the following factor is obtained:

$$K_T = -0.0034/°C \quad \text{(MOR Tests)}$$

Figure 3.10 illustrates the accuracy in using the MSR data to predict the results of the MOE and MOR static tests.

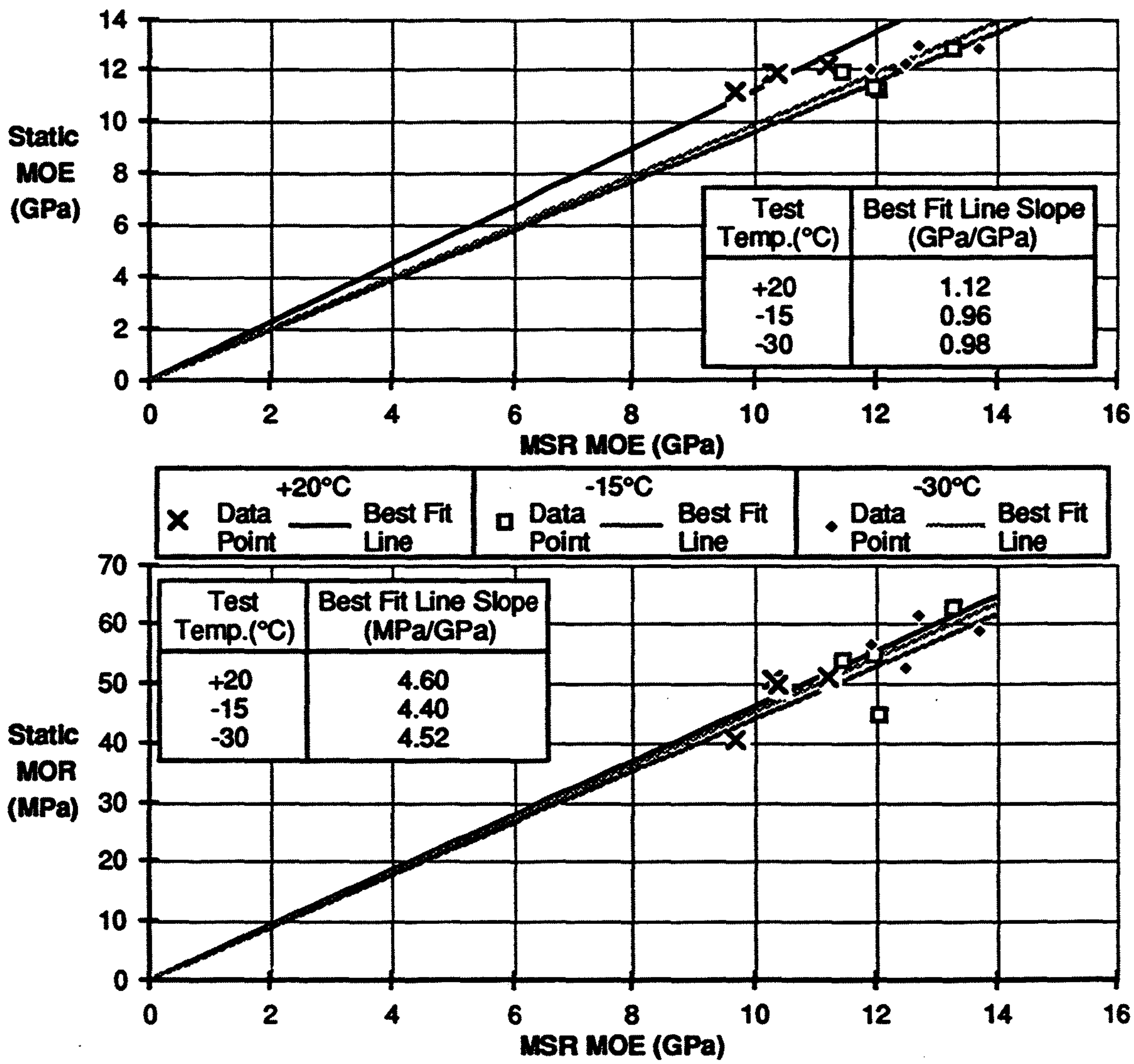


Figure 3.10. Static MOE and MOR vs. MSR MOE.

4.0 SUMMARY

The results of this test program indicated that a temperature correction should be applied to lumber that is MSR graded at low temperatures in order to predict the MOE and MOR at room temperature. The values of MOE and MOR increased with a decrease in temperature, but the increase appeared to vary somewhat. The MSR testing indicated an assumed linear change of MOE with temperature to be $K_T \approx -0.39\%/°C$, and that of the static tests to be $K_T \approx -0.13\%/°C$. The change in MOR with temperature was close to the changes observed for the MSR MOE changes. That is, the correction factor for MOR is $K_T \approx -0.34\%/°C$.

Previous stiffness correction attempts for temperature variations[4] have shown the MOE to vary considerably, but that an average correction of $K_T \approx -0.25\%/°C$ was appropriate for lumber samples having moisture contents within the range of values measured in this test program (14 to 19%).

The static MOE results at room temperature were higher than those measured during MSR testing. The reasons for this are not known, but speculation may lead one to believe that perhaps more static testing is required to produce a statistically acceptable data set. The differences in MOE results at room temperature are the prime reason for the differences in the correction factors given in the previous paragraph.

As expected, the 2100f and 1650f lumber grades (previously stiffness graded) showed a relatively uniform increase in MOE with a decrease in temperature. MOE for the "J" and Standard and Better grades did not follow a consistent trend with temperature.

The correction factors, K_T, for temperature ranges from -30°C to +20°C and from -15°C to +20°C were about two times the K_T values obtained from a temperature change from -30°C to -15°C. That is, per degree Celsius, the lumber stiffness did not appear to change much once it was frozen, but a large change was noticed as the lumber changed from above freezing temperatures to below freezing temperatures. This implies that there may be a dramatic change, or abrupt increase, in stiffness as a result of the phase change from liquid to solid of the moisture in the lumber. For the static MOE tests, $K_T \approx -0.13\%/°C$ when the temperature change involves a phase change, but $K_T \approx -0.08\%/°C$ when the temperature change does not include a phase change. Similarly, the K_T factors for the MSR tests are -0.39%/°C and -0.20%/°C, respectively. The effect of moisture phase change on stiffness is one notable area for further research.

The effect of freezing and thawing the lumber specimens (one cooling cycle) was briefly investigated through a second series of room temperature tests performed after the -15°C and -30°C test series. The second set of +20°C static MOE tests resulted in an 8% decrease, but the MSR MOE values did not result in any noticeable change. The static MOE decrease can be attributed to the small number of tests performed, and the MSR MOE data, indicating no change in MOE, should be considered the statistically acceptable data set. There was no noticeable change in MOR as a result of the cooling cycle.

5.0 REFERENCES

1. National Lumber Grades Authority. 1987. NLGA Special Products Standard for Machine Stress Rated Lumber. SPS 2, National Lumber Grades Authority, Vancouver, April.

2. ASTM D198. 1984. Standard Methods of Static Tests of Timbers in Structural Sizes. ASTM Designation D 198 - 84. American Society for Testing and Materials, April.

3. Bach, L. 1993. Cold Temperature MSR Data Report. Report prepared for the Centre for Frontier Engineering Research by the Wood Products Engineering Department of the Alberta Research Council, March.

4. Lum, C. 1990. Effect of Cold Lumber on MSR Production: Analysis of 1987/88 Mill Data. Report prepared for Forestry Canada by Forintek Canada Corp., March.