AN ABSTRACT OF THE THESIS OF

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Title: Effect of Temperature on MOE and MOR of Structural Panels
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James B. Wilson

Oriented strand board is a panel product used in structural applications in home construction much like plywood, yet little is known of the effect of temperature and moisture content on its performance. The objective of this study is to study these effects on oriented strand board and for comparative purposes on plywood.

Commercial panels of two types of oriented strand board (OSB) were studied, one bonded with pheno formaldehyde and the other with isocyanate, yet having been manufactured on the same production line. The comparative panels of commercial plywood were made of Douglas-fir and of sheathing grade.

The study parameters included five levels of temperature (35, 72, 100, 150, and 200°F) and two levels of moisture content (0 and 7%, oven-dry basis). The number of test replications was five for each parameter. Samples measuring 3 x 14 inches were tested in three point bending to determine the effect of the study parameters on their modulus of rupture (strength) and modulus of elasticity (stiffness). The data were analyzed statistically considering a two-factor experiment with a completely randomized design having five

replications.

The conclusions for the range of the study parameters were that when the panels were oven-dry (0% moisture content), there was no statistically significant correlation of either modulus of rupture (MOR) or modulus of elasticity (MOE) with change in temperature. However, when the panels were tested at 7% moisture content there was a significant decrease in both MOR and MOE with an increase in temperature. For example, in going from a temperature of 72 to 200°F there was an approximate decrease in MOR of 30% for both the plywood and the isocyanate bonded OSB, and 40% for the phenolic bonded OSB and a decrease in MOE of 20% for plywood, and 30% for the isocyanate bonded OSB, and 35% for the phenolic bonded OSB.

EFFECT OF TEMPERATURE ON MOE AND MOR OF STRUCTURAL PANELS

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EFFECT OF TEMPERATURE ON MOE AND MOR OF STRUCTURAL PANELS

I. INTRODUCTION

Moisture content and temperature both have important effects on mechanical properties of wood and wood products. Many researchers (Sulzberger 1953; Hann, Black and Blomguist 1963; Lehmann 1978; Pozgaj 1979; Chow and Redmond 1981) have investigated the effects of moisture change and the combined effects of moisture and temperature change on the mechanical properties of wood. Results of the research usually showed that static strength decreased with an increase in either moisture content or temperature. The combination of high moisture content and high temperature has the greatest effect on the strength of wood products.

There is lack of information on the effect of temperature on modulus of elasticity (MOE) and modulus of rupture (MOR) on structural panel products such as plywood, oriented strand board (OSB) whether bonded with phenolic formaldehyde (PF) or isocyanate (ISO) adhesives.

Physical and mechanical properties of wood composites, although similar to those of solid wood, are dependent on the species of their components and the type of resin used. Factors affecting the performance of wood composites, other than raw material parameters, include the manufacturing process and environmental conditions of the product in-service. Raw material and board making process factors include wood species, resin type, wood density, flake configuration, resin distribution, pressing time, hot pressing temperature, and the distribution of density within a panel. One of the environmental condition factors is temperature which is a study parameter of this study.

Oriented stand board is a newly developed composite board intended for structural panel markets such as siding, roof, and wall sheathing. In-service use of these types of panel products can experience temperatures ranging from extremes of -50 to 80°C within habitable regions. Since these panel products must perform to certain structural standards, it is important to know how these in-service temperatures can effect their structural performance.

II. OBJECTIVES

The objective of this study is to determine the effect of temperature on modulus of elasticity (stiffness) and modulus of rupture (strength) on composite structural panels. These effects need to be understood and taken into account in the structural use of these panel products.

Three types of wood composites were examined: they were (1) a phenolic-bonded oriented strand waferboard, (2) an isocyanate-bonded oriented strand waferboard and (3) a phenolic-bonded plywood. All test samples were cut from commercial boards. Both of the OSB panels were made on the same production line, using the same wood furnish and target panel density and were purchased from a local retail yard.

III. LITERATURE REVIEW

1. Effect of Moisture Content and Temperature on the Mechanical Properties of Solid Wood

Sulzberger (1953) published experimental results on the strength of wood, plywood and glued joints as affected by variations in temperature and moisture content on various species. In his experiments, the environmental conditions of temperature and moisture content were controlled by placing the testing equipment and specimen in a conditioned chamber as shown in Figure 3.1.

Static bending tests (center-point loading) were made in the environmentally controlled chamber on 10 in.x 5/8 in.x 5/8 in. specimens, over an 8 in. span at a constant rate of loading of approximately 70 lb./min, with the load being applied to the radial face. The test levels for moisture: 8, 12 and 20%, for temperatures: -20, 0, 20, 40 and 60°C.

Sulzberger's data showed that modulus of elasticity decreased with an increase in temperature (see Figure 3.2). The relationship of modulus of elasticity and moisture content was either linear or curvilinear. The linear components of the temperature effect, for all species and moisture contents, were significant at the one percent level of probability. The data was normalized to better show this relationship by making the modulus of elasticity as 100 percent at a temperature of

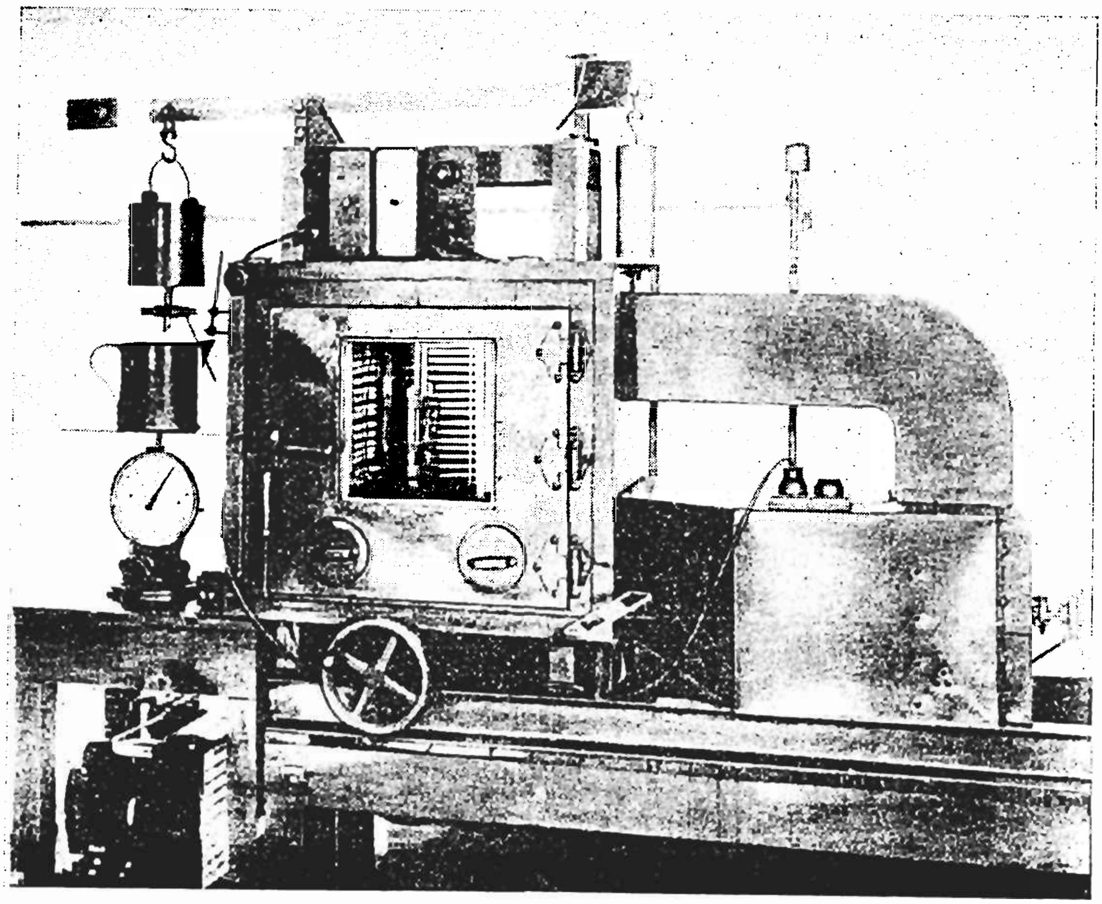

Figure 3.1 Air-conditioned test machine
Source: Sulzberder (1953)

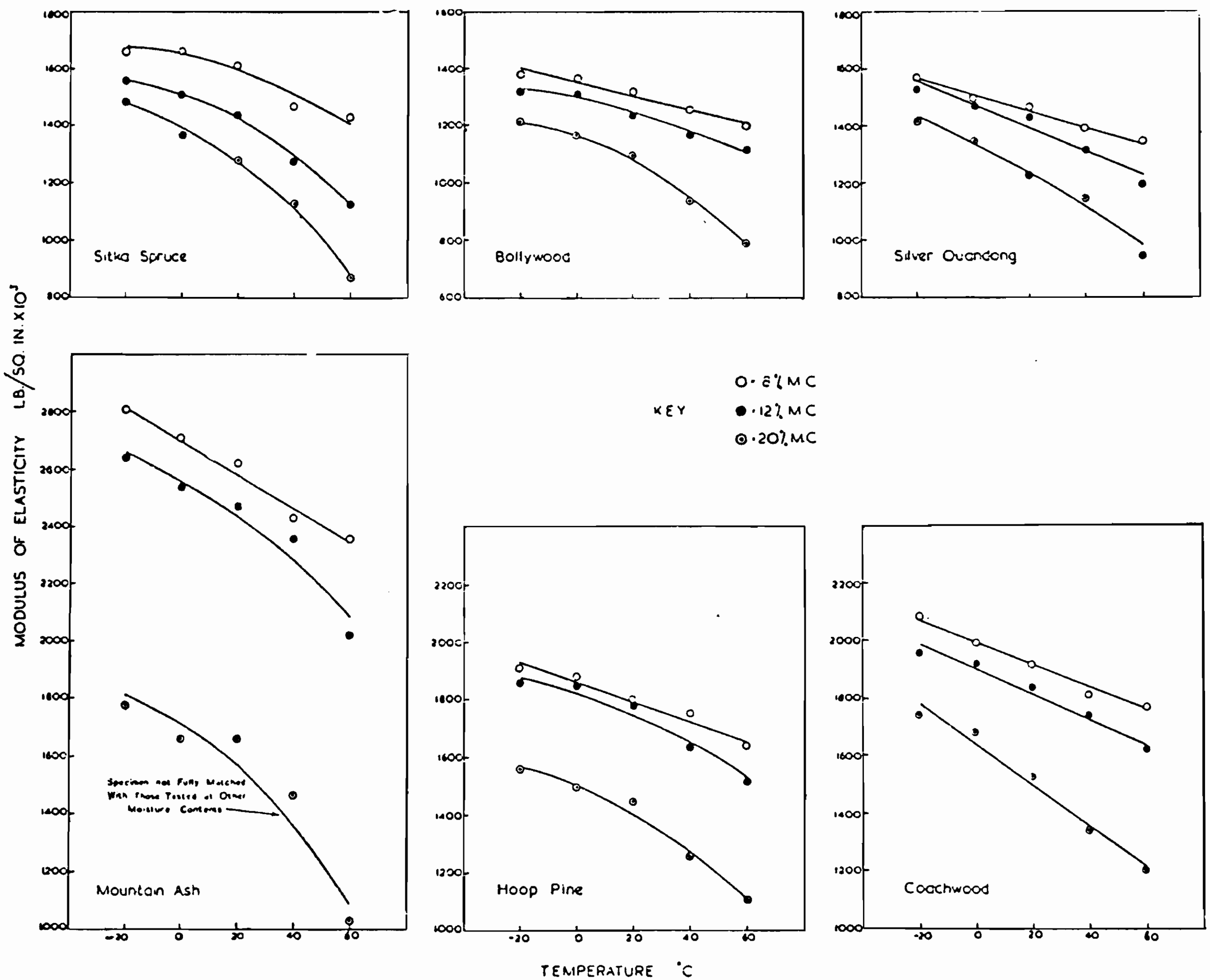

Figure 3.2 The effect of T at various MC on MOE of wood
Source: Sulzberger 1953

20°C, as shown in Figure 3.3. These curves, representing an average result for all species, conform to the general trend of temperature effect noted earlier, namely linearity of the strength-temperature relation at zero moisture content and increasingly becoming curvilinearity as moisture content increases. The effect of temperature on modulus of elasticity is slight at zero moisture content but appreciable at high moisture contents approaching the fiber saturation point of approximately 25% MC.

Gerhards (1982) summarized the relevant literature on the effect of moisture content and temperature on several mechanical properties of clear wood. The article covered a variety of species and specimen sizes, test conditions and analyses, and it developed common bases for the data to permit a direct comparison of moisture or temperature effects only. The following is a summary of these effect.

Modulus of elasticity parallel-to-the-grain:

The relative effect of moisture content on modulus of elasticity at room temperature is summarized in Figure 3.4 by Gerhards for the results of four researchers (Kufner 1978; Schneider 1971; Sulzberger 1953; Wilson 1932).

The effect of temperature on modulus of elasticity for wood near zero percent moisture content (Figure 3.5A) is illustrated with results from eight studies (Bernier and Kiline 1968; Ishida 1954; Kitahara and Matsumoto 1974; Kollmann 1960; Okuyama 1974; Partl and Strassler; Schaffer

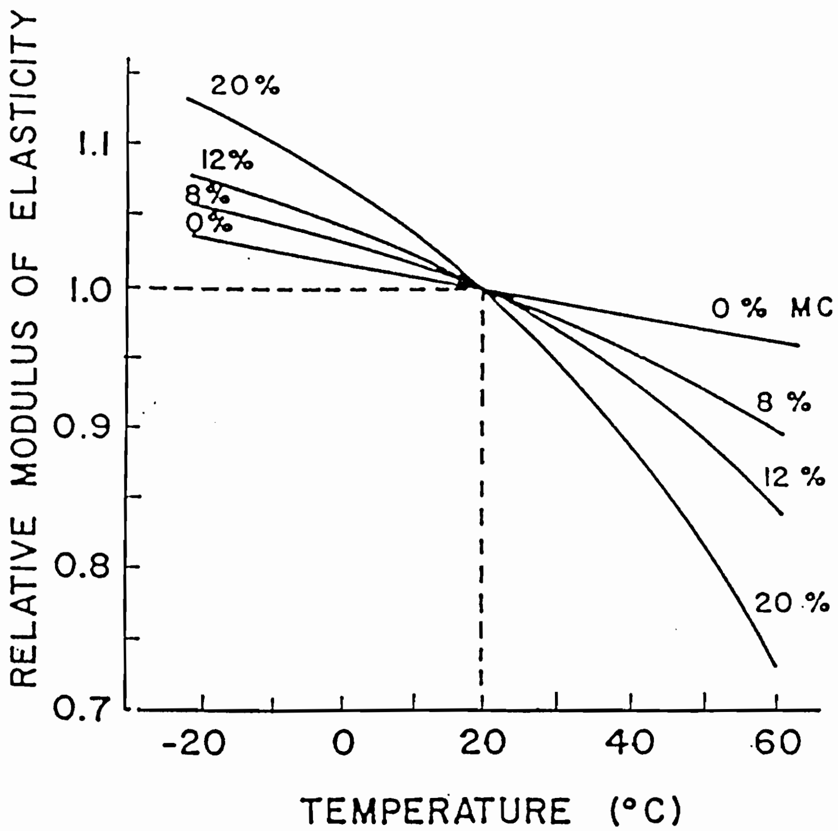

Figure 3.3 The effect of T on MOE in static bending
Source: Sulzberger (1953)

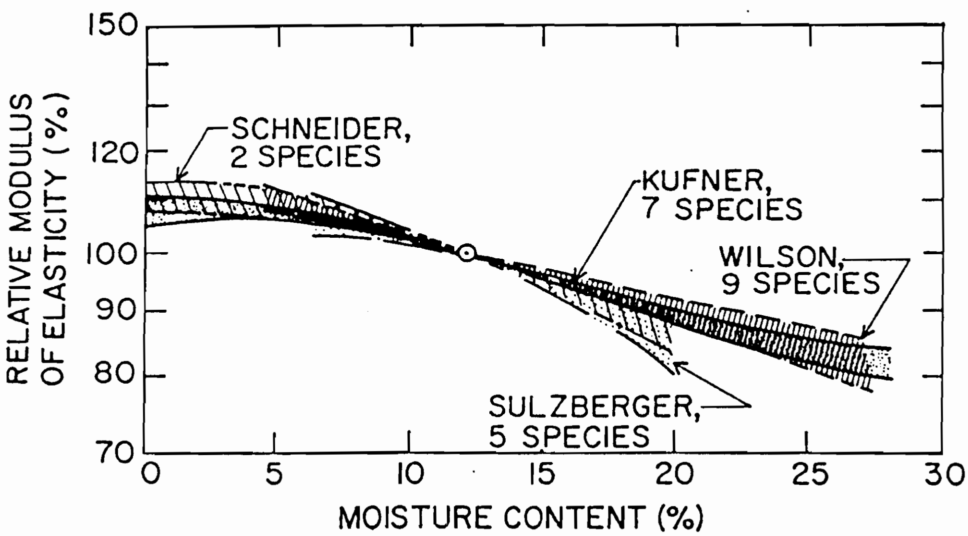

Figure 3.4 Effect of MC on MOE parallel to the grain at 20°C,12%MC
Source: Gerhards (1979)

1970; Sellevold et al. 1975). The effect of temperature on MOE within the hygroscopic range does not appear to be as well established as for zero percent moisture content. Variation among results for nine studies (Comben 1964; Ishida 1954; James 1961; Kitahara and Matsumoto 1974; Noack and Geissen 1976; Preusser 1968; Sano 1961; Sellevold et al.1975; Sulzberger 1953) that contained data on temperature effect for 11-15% moisture content was greater than that at zero percent moisture content.

Study results in other moisture content ranges below 11 percent and above 15 percent are insufficient to warrant separate figures; however, they are of interest when compared to those given in Figure 3.5B.

The effect of temperature on wood above fiber saturation in green or wet conditions (Figure 3.5C) from-200 to 0°C is definitely greater than the effect on wood below fiber saturation (Figure 3.5A,B), whereas, above 0°C the data are the same.

Modulus of elasticity perpendicular-to-the-grain:

Data on the effect of moisture content on modulus of elasticity perpendicular-to-the-grain near room temperature gleaned from 4 reports (Ellwood 1954; Greenhill 1936; Kadita et al. 1961; Siimes 1967) are summarized in Figure 3.6. The modulus of elasticity perpendicular to grain trends to have both a greater moisture effect and a much greater variation in results than modulus of elasticity parallel.

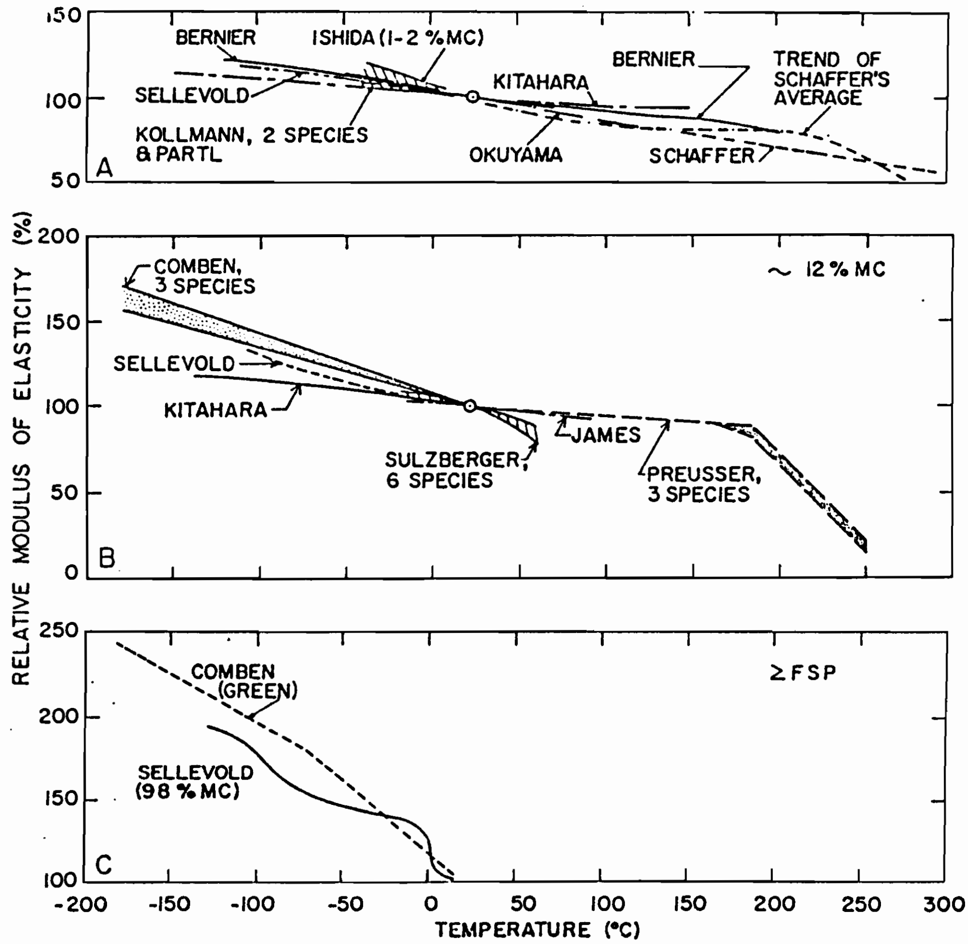

Figure 3.5 Effect of T on MOE parallel to the grain, A:0%,B:12%,C:>FSP,at 20°C
Source: Gerhards (1979)

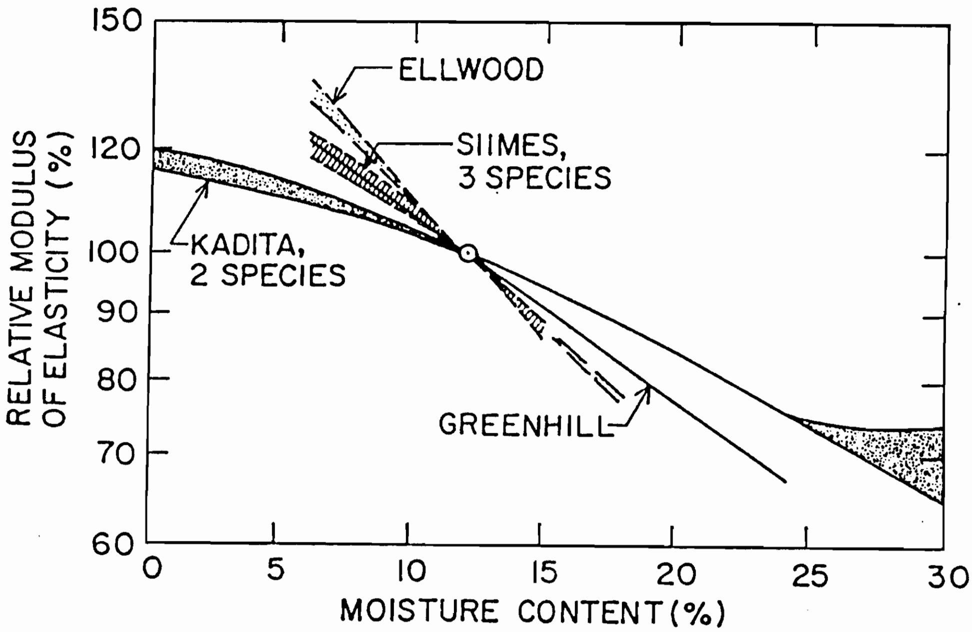

Figure 3.6 Effect of MC on MOE perpendicular to the grain at 20°C,12%MC
Source: Gerhards (1979)

Eight reports (Byvshykh 1959; Ellwood 1954; Greenhill 1936; Kitahara and Suematsu 1955; Noack and Geissen 1976; Okuyama et al. 1977; Siimes 1967; Yonungs 1957) evaluated the effect of temperature on modulus of elasticity perpendicular-to-the-grain and summarized in Figure 3.7.

On the basis of these data, moisture has the least effect on MOE and MOR measurements parallel to the grain. Temperature generally tends to have greater effects at higher moisture contents.

Beall's (1982) article entitled "Effect of temperature on the structural uses of wood and wood products" shows that the effect of temperature on the strength of wood is generally secondary to moisture content effects on axial, transverse, and shear moduli.

For modulus of elasticity perpendicular to grain, there was no significant change with temperature at zero percent moisture content but at the fiber saturation point the change was 0.012 percent per°C. The combined modulus of elasticity from a number of studies and types of tests also shows a general linearity to about 100°C, approaching the onset of thermal degradation.(see Figure 3.8)

2. Other Wood Product Type

a Particleboard

Yang and Haygreen (1971) tested a commercial three-

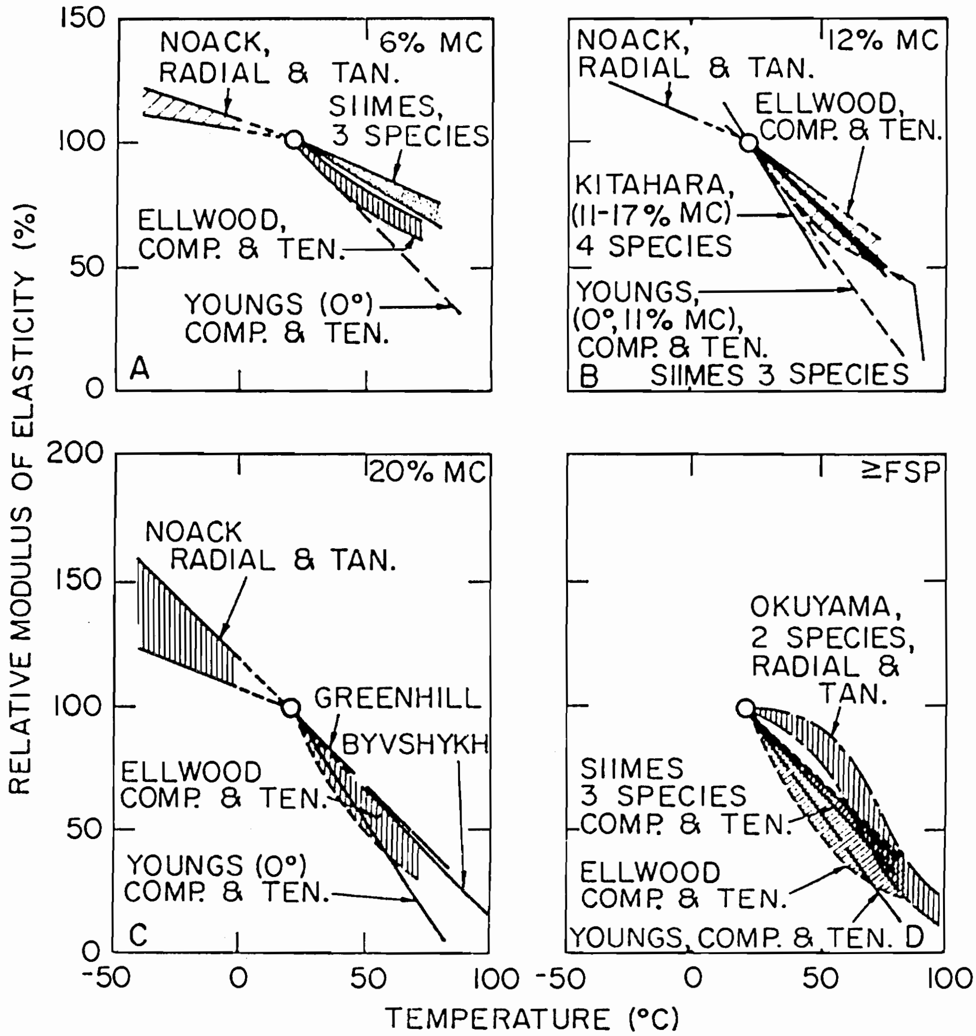

Figure 3.7 Effect of T on MOE perpendicular to the grain, A:6%MC, B:12%, C:20%MC, D:>FSP, at 20°C
Source: Gerhards (1979)

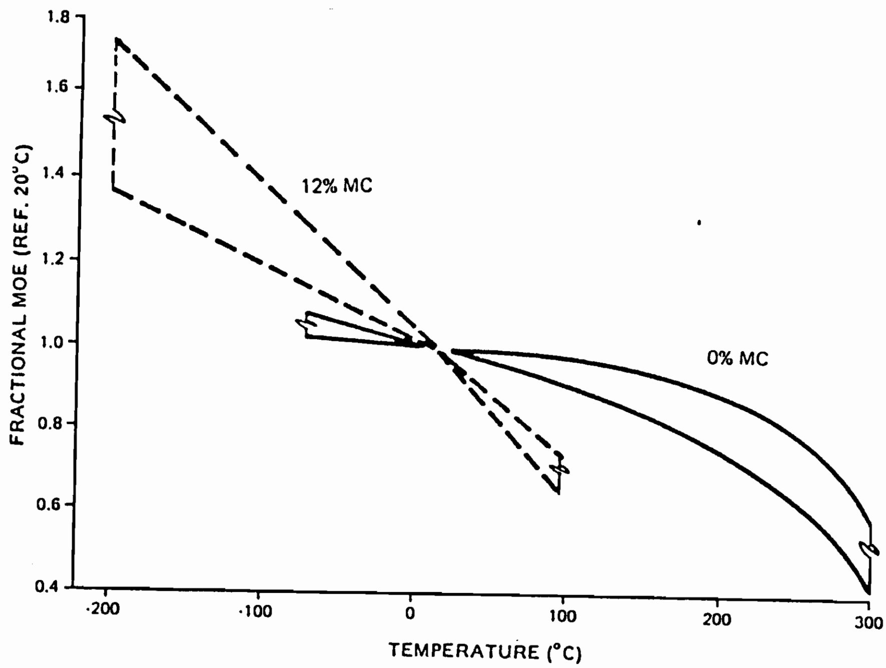

Figure 3.8 Effect of T on the combined MOE
Source: Beall (1982)

layer exterior-type particleboard in static bending for immediate strength over the range of 0 to 71°C. Changes in modulus of rupture with temperature were approximately -0.38 percent per°C at 7 percent MC and -0.58 percent per°C at 10 percent MC when referenced to 20°C, as shown in Table 3.1. These values are not substantially different from those for solid wood.

b Fiberboard and Veneer Laminate

Chow and Redmond (1980) studied the effect of humidity and temperature effects on MOR and MOE of medium density fiberboard that had veneer laminated surfaces.

The effect of relative humidity (RH) on MOR and MOE at a constant temperature is shown in Figures 3.9 and 3.10. This shows that with a constant temperature remaining constant relative humidity had a strong influence on both MOR and MOE for all specimens tested. All materials lost 5, 10, and 20 percent of initial MOE values, and 10, 20, and 40 percent of MOR when the humidity was increased from 50 to 64, 78 to 92, percent, respectively,

Chow and Redmond reported that the effect of temperature on MOR and MOE showed decreases in average MOR and MOE for all materials with an increase of temperature, either from 50 to 100 F or from 75 to 100 F, as shown in Figures 3.11 and 3.12.

Nominal temper-ature °F	Actual temper-ature °F	Moisture content %	Modulus of rupture psi		Deflection at failure (inch)		Tangent modulus (10^5 psi)					
							at 252 psi		at 755 psi		at 1258 psi	
			Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean	C.V.
LOW MOISTURE CONTENT												
32	23.1	7.31	3002	10.22	0.301	8.73	7.491	7.50	7.43	7.96	7.32	8.98
72	73.4	7.43	2635	11.14	0.353	8.07	5.65	9.21	5.59	9.19	5.43	8.72
120	118.6	7.41	2352	9.52	0.396	8.21	4.70	8.78	4.58	9.56	4.25	12.04
160	160.0	7.33	2243	11.63	0.425	5.71	4.31	11.87	4.24	10.15	3.82	13.04
HIGH MOISTURE CONTENT												
32	33.8	10.16	2737	12.65	0.326	11.68	6.54	6.34	6.29	7.52	5.88	9.05
72	75.2	10.13	2183	15.31	0.365	8.54	4.86	6.52	4.70	7.69	4.22	10.81
120	122.0	10.19	1951	8.96	0.466	9.76	3.79	6.96	3.40	6.81	2.77	10.26
160	162.3	10.16	1703	7.98	0.497	7.88	3.26	6.06	2.76	7.67	2.11	11.89

Table 3.1 Results of staic bending tests at four temperature levels and two moisture content
Source: Yang and Haygreen

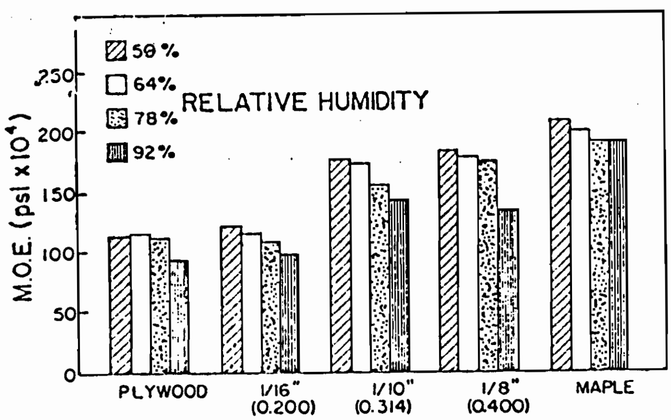

Figure 3.9 Effect of four RHs on the average MOE of plywood, 3 maple-veneered MDFs, and maple lumber
Source: Chow and Redmond (1980)

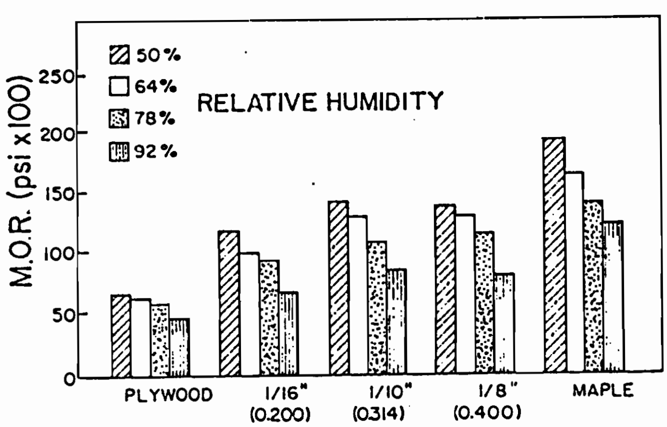

Figure 3.10 Effect of four RHs on the average MOR of plywood, 3 maple-veneered MDFs, and maple lumber
Source: Chow and Redmond (1980)

3 Conclusions Drawn From Literature

The following main conclusions might be considered as a result of this literature review:

1. At the same moisture content the strength properties decrease with an increase in temperature. At higher moisture contents, the effect increases substantially.
2. The combination of high moisture content and high temperature has the greatest effect on the strength of wood products.
3. The effect of temperature on modulus of elasticity is slight at zero percent moisture content.
4. Estimates of strength loss with change in temperature are 0.07%/°C at 0% MC from the -185 to 65°C range and about 0.3%/ °C at 12% MC from the -185 to 65°C range. (Beall, F. C. 1982)

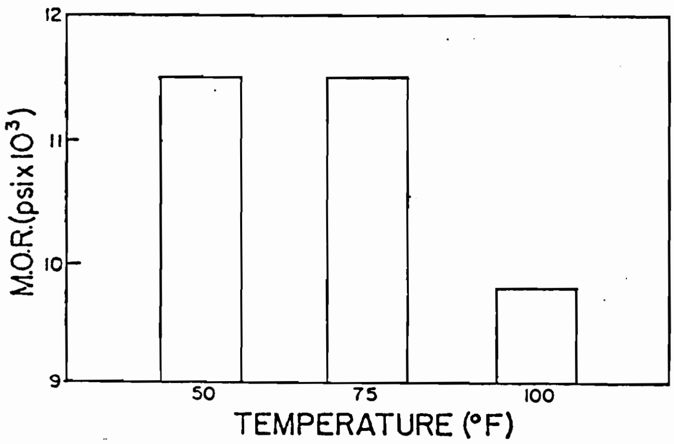

Figure 3.11 Effect of three temperatures on the average MOR of maple-veneered MDF composite panels
Source: Chow and Redmond

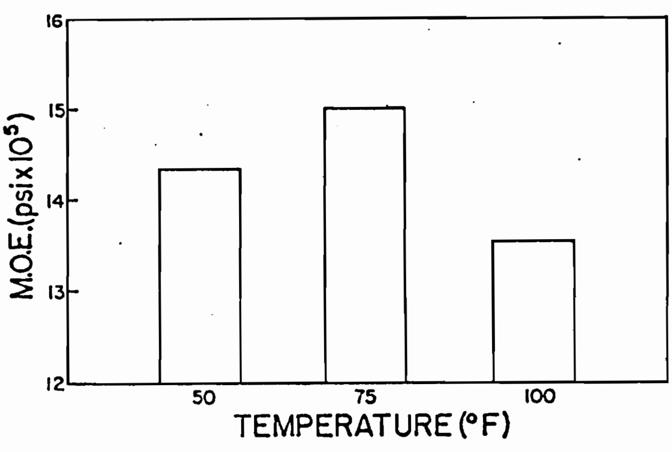

Figure 3.12 Effect of three temperatures on the average MOE of maple-veneered MDF composite panels
Source: Chow and Redmond

IV. METHODOLOGY

1. Material

The test samples were prepared from commercially made oriented strand board (oriented faces with a random core) and plywood. Two types of oriented strand boards (OSB) were studied, one bonded with isocyantate (ISO) and the other with pheno-formaldehyde (PF). Further details on the three types of panel tested are given Table 4.1.

Table 4.1 Specifications and Properties of the Materials

Type of Product	ISO-OSB	PF-OSB	Plywood
Species	Aspen	Aspen	D-fir
Thickness(in)	0.468	0.445	0.448
CV(%)	4.96	0.77	1.64
Density(pcf)	40.39	39.22	34.82
CV(%)	6.93	7.70	2.2
MOE (psi)	1,050,554	976,395	1,132,020
CV(%)	12.2	13.9	0.51
MOR (psi)	6321	5610	6322
CV(%)	20.1	24.88	4.92
MC(%)	5.22	4.7	7.63
CV(%)	5.06	6.17	5.39

The data were obtained by testing in room conditions which are represented by the EMC of the samples tested.

2. Specimens Preparation

Test specimens measuring 3 inches wide by 14 inches long were cut from the panel. The length of each sample was either in the machine direction of the OSB panels or in the grain direction of the face veneer of the plywood panel. Five levels of temperatures, 35, 72, 100, 150, and 200°F were examined at two levels of moisture content, 0 and 7 percent (ovendry basis).

The test replication was five for each type of test specimen, temperature, and moisture content condition.

3. Experimental Procedure and Equipment

A standard three point bending test was used to determine MOE and MOR. Modulus of elasticity and modulus of rupture were tested using an Instron machine with the testing jig located within a temperature controlled chamber as shown in Figure 4.1. The test procedure was according to ASTM D-1037 standard. The bending test span was 12 inches long and the loading rate was 0.2 in/min.

The temperature controlled chamber (Figure 4.2) was made of composite panels consisting of plywood, hardboard, heat resistant closed cell foam insulation and silver paper. The temperature was controlled to ± 2°F for the test sample.

The ovendry samples (zero percent MC) were conditioned in an oven for 24 hours at 212°F then cooled down to the desired temperature prior to testing. The samples for 7 percent MC were conditioned at 70°F and 65 percent RH for

Figure 4.1 The Instron machine and Temperature controlled chamber

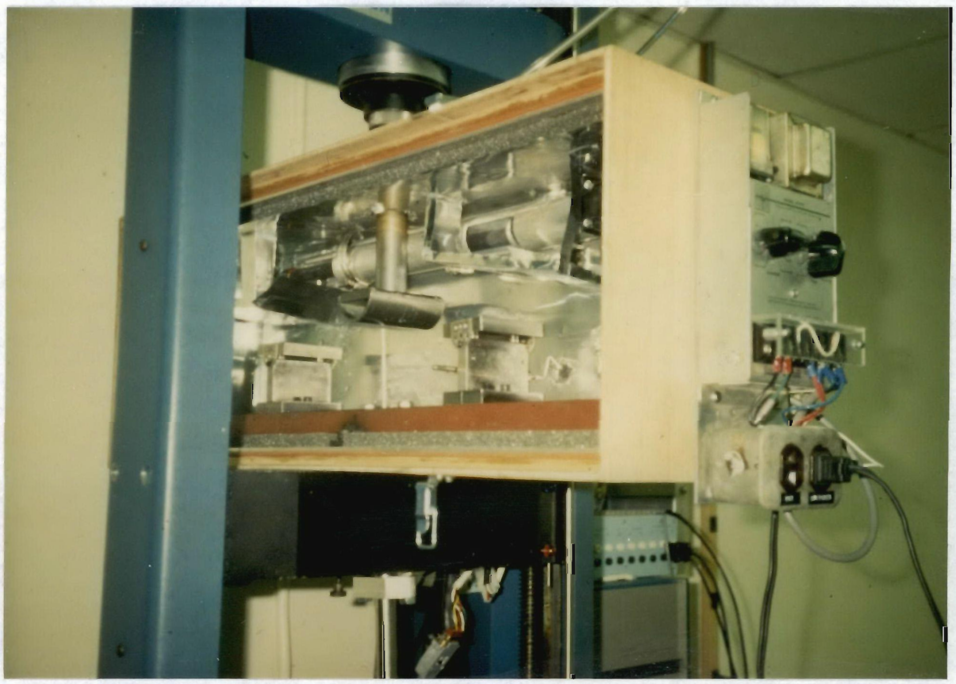

Figure 4.2 The Temperature controlled chamber

two weeks prior to testing. All samples were keep at their desired moisture content by wrapping them in plastic. The time to heat the samples to 150°F was 1.5 hours and to 200°F was 2 hours. The oven temperature was set at 10°F higher than the target temperature. To determine moisture content, samples were weighted immediately after testing. The moisture content change (for only the 7% MC samples) during heating and testing was -0.99% MC (the average for the three types of material) at 200°F and was -0.28% MC at 150°F. The loss of sample moisture was much less for testing at 35 and 100°F. The moisture content was controlled to about ± 0.8 percent.

Load-deflection data for the bending test was determined by recording the voltage output from the load cell and from a LVDT (Linear Variable Differential Transformer) for displacement. A Campbell Scientific CR7X data logger was used to record the data. Analysis was then done by transferring the data to an IBM PC and applying the appropriate software analysis.

V. RESULTS AND ANALYSIS

Statistical design and analysis were applied to this experiment. This is a two-factor experiment, using a completely randomized design with five replications. The model was

$$Y_{ijk}=U+T_i+M_j+TM_{ij}+e_{ijk} \qquad [5.1]$$

$i=1,2,3,4,5 \quad j=1,2 \quad k=1,2,3,4,5$

where U represents overall mean yield, T_i represents a temperature effect, M_j represents a moisture content effect, TM_{ij} represents added effect of the combination of the ith level of T with jth level of M and e_{ijk} represents random error.

Selected for the study were five temperatures (°F):

$t_1=35$, $t_2=72$, $t_3=100$, $t_4=150$, $t_5=200$

and two moisture contents (%):

$m_1=0$, $m_2=7$

The experimental data is presented first for MOE as affected by temperature and MC and then for MOR as affected by these same variables. In all cases, there was no effect of temperature on either MOE or MOR when the samples were 0% MC, whereas, there was an effect for samples at 7% MC.

1. Modulus of Elasticity in Static Bending

The results of the ANOVA for MOE (see Tables 5.1 through 5.3) showed that two main factors, temperature and moisture content, had significant interactions at the 0.01 and 0.05 levels for all three panel types.

The effect of temperature for all three panel types at zero percent moisture content was not significant between different temperatures (see Tables A1, A3 and A5 in Appendix) at either the one percent or five percent level of probability. The graphs of means for MOE, shown in Figures 5.1 through 5.3, show that the effect of temperature is slight at zero percent moisture content. The effect of temperature on MOE at seven percent moisture content shows a significant decrease with an increase in temperature (at the 0.01 level of probability, shown in Tables A2, A4 and A6 in Appendix).

The test of the slope of regression line also supports this conclusion, shown in Tables B1 through B6 in Appendix. The slope of regression line for all three panel types shows a strong linear relationship between MOE and temperature at a level of significance 0.01 at 7% moisture content and shows no linear relationship between MOE and temperature at 0% moisture content.

At seven percent moisture content, an increase in temperature has a considerable weakening effect on modulus of elasticity of the panels. This can be illustrated by normalizing the MOE value for each panel type to 1.0 at 72 °F and plotting the average fractional modulus of elasticity for each moisture content against temperature, as shown in

Table 5.1 ISO-MOE Analysis of Variance Report

ANOVA Table for Response Variable: MOE

Source	DF	Sum-Squares	Mean Square	F-Ratio	
T	4	36.2E+10	9.0E+10	5.14	**
LR	1	24.9E+10	24.9E+10	14.15	**
LOF	3	11.3E+10	3.8E+10	2.14	
MC	1	0.9E+10	0.9E+10	0.51	
T&MC	4	28.6E+10	7.2E+10	4.07	**
T(LR)*MC	1	26.2E+10	26.2E+10	14.92	**
LOF(T&MC)	3	2.4E+10	0.8E+10	0.45	
Error	40	70.4E+10	1.8E+10		
Total	49	136.0E+10			

* Significant at the 5% level of probability
** Significant at the 1% level of probability
LR - Linear Regression
LOF - Lack of fit

Means of ISO MOE (psi)

		Temperature (F)				
		35	72	100	150	200
	0%	993388	876732	886851	843562	1016658
MC	7%	1124032	993624	866948	766176	732184

Table 5.2 PF-MOE Analysis of Variance Report

ANOVA Table for Response Variable: MOE

Source	DF	Sum-Squares	Mean Square	F-Ratio	
T	4	39.3E+10	9.8E+10	5.98	**
LR	1	35.4E+10	35.4E+10	21.5	**
LOF	3	3.9E+10	1.3E+10	0.79	
MC	1	4.3E+10	4.3E+10	2.59	
T&MC	4	18.7E+10	4.7E+10	2.84	*
T(LR)*MC	1	14.1E+10	14.1E+10	8.56	**
LOF(T&MC)	3	4.6E+10	1.5E+10	0.93	
Error	40	65.8E+10	1.6E+10		
Total	49	128.0E+10			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means of PF MOE (psi)

		Temperature (F)				
		35	72	100	150	200
	0%	887640	820600	845354	763648	806167
MC	7%	924602	949176	735214	617342	605354

Table 5.3 PLY-MOE Analysis of Variance Report

ANOVA Table for Response Variable: MOE

Source	DF	Sum-Squares	Mean Square	F-Ratio	
T	4	16.8E+10	4.2E+10	2.81	*
LR	1	12.4E+10	12.4E+10	8.28	**
LOF	3	4.5E+10	1.5E+10	0.99	
MC	1	2.1E+10	2.1E+10	1.41	
T&MC	4	16.1E+10	4.0E+10	2.69	*
T(LR)*MC	1	14.3E+10	14.3E+10	9.53	**
LOF(T&MC)	3	1.8E+10	0.6E+10	0.41	
Error	40	59.8E+10	1.5E+10		
Total	49	94.8E+10			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means of PLY MOE (psi)

		Temperature (F)				
		35	72	100	150	200
	0%	1057427	1088180	1097284	1081468	1073578
MC	7%	1133280	1132020	1086034	1012812	828168

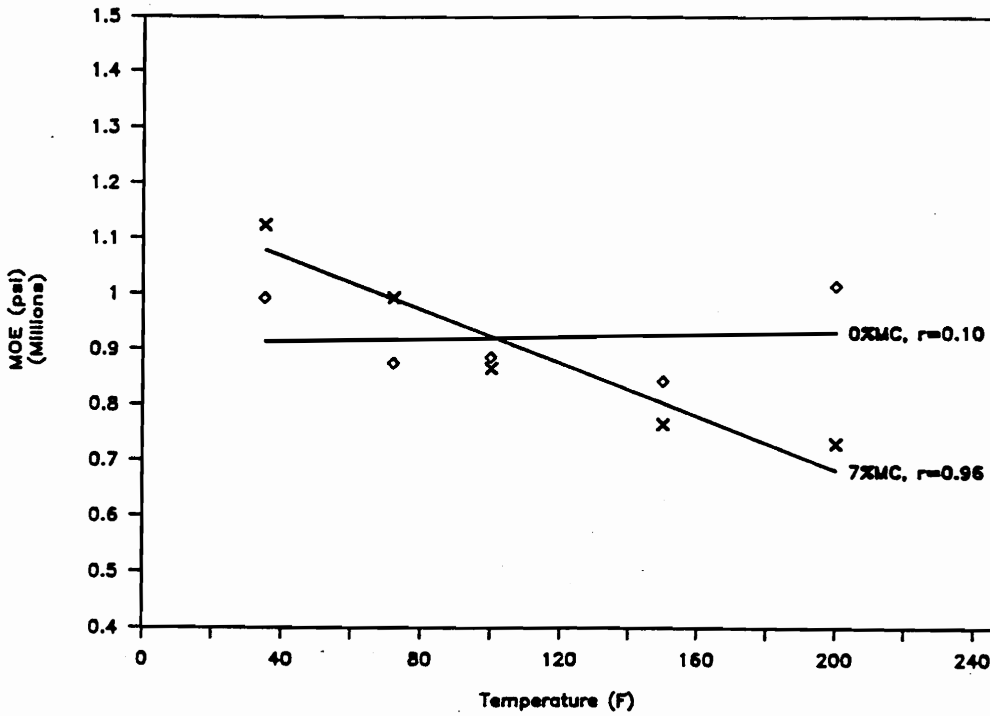

Figure 5.1 Mean of MOE (ISO)

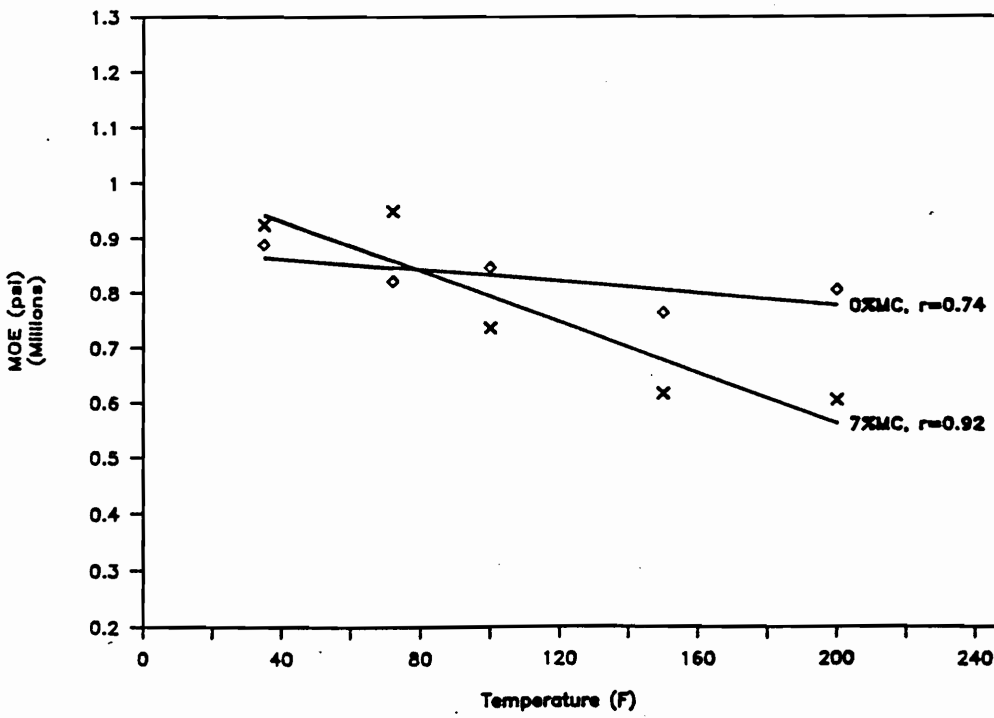

Figure 5.2 Mean of MOE (PF)

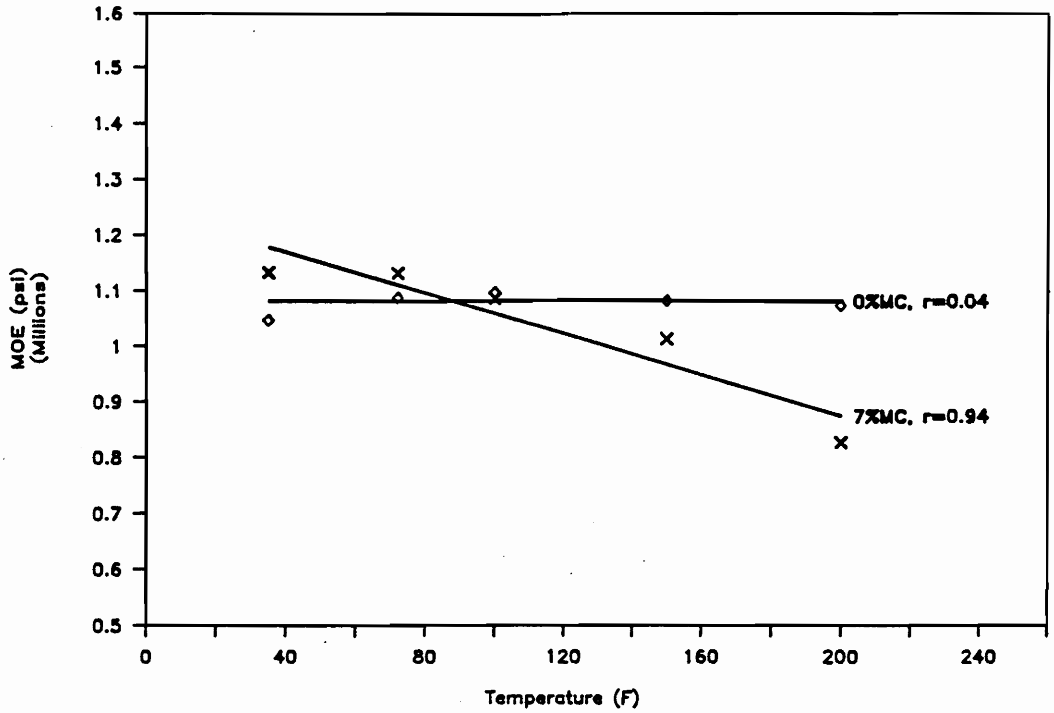

Figure 5.3 Mean of MOE (PLY)

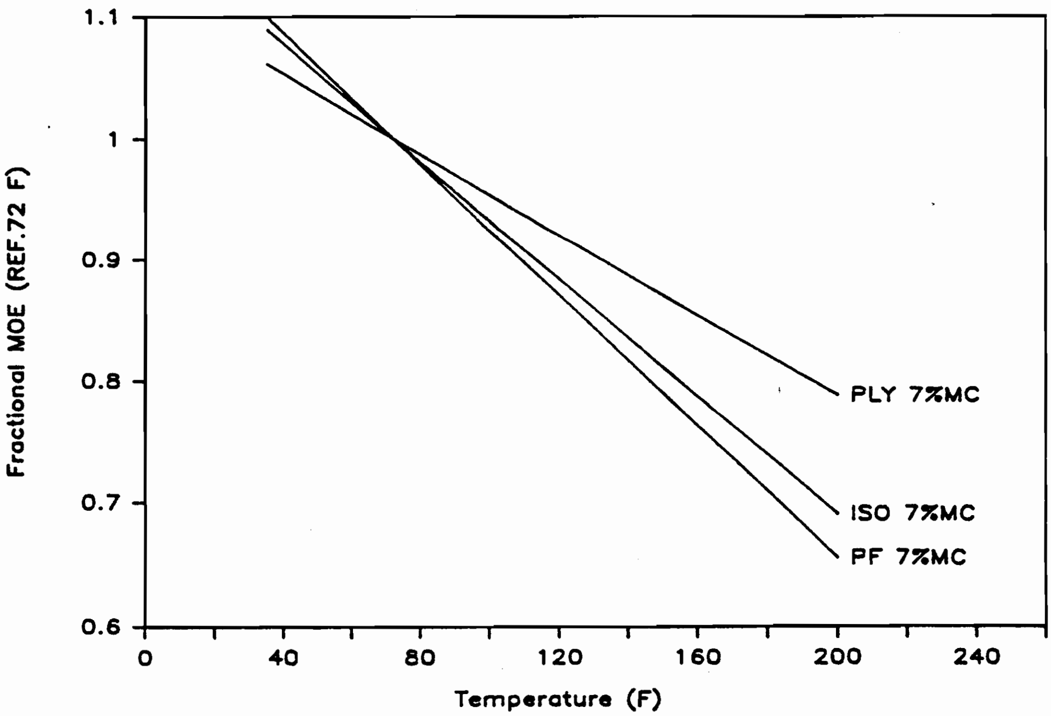

Figure 5.4 MOE at 7%MC

Figure 5.4. MOE at a constant seven percent moisture content decrease linearly with an increase in temperature. The relation may be written as

$$E_{t1} = E_{t2} - de(t_1 - t_2) \qquad [5.2]$$

where E_{t1} is MOE at 7% MC and t_1 °F, and de is the modulus of the regression coefficient of MOE on temperature. Equation [5.2] is valid in the range 35 °F to 200 °F for all three panel types. The strength-temperature coefficient:

de=0.00255 (ISO & PF)

de=0.00165 (PLY)

The stiffness E_{t1} at a temperature t_1 °F is related to the stiffness E_{t2} at a temperature t_2 °F.

2. Modulus of Rupture in Static Bending

From analyses of variance reports, (Tables 5.4 through 5.6) the interaction between temperature and moisture content was significant at the 0.05 level for PF, and not obvious for ISO and PLY in this modulus of rupture test.

The effect of temperature on MOR at zero percent moisture content as shown in Figures 5.5 through 5.7 behaved similar to its effect on MOE. There was no significant change on modulus of rupture at zero percent moisture. However, at seven percent moisture content, there was a significant trend showing a decrease in temperature, shown in Tables A7 through A12 in Appendix.

Table 5.4 ISO-MOR Analysis of Variance Report

ANOVA Table for Response Variable: MOR

Source	DF	Sum-Squares	Mean Square	F-Ratio	
T	4	22046052	5511513	3.47	*
LR	1	15689521	15689521	9.87	**
LOF	3	6356531	2118844	1.33	
MC	1	508032	508032	0.32	
T&MC	4	7845148	1961287	1.23	
T(LR)*MC	1	2436721	2436721	1.53	
LOF(T&MC)	3	5408427	1802809	1.13	
Error	40	63583560	1589589		
Total	49	93982792			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means of ISO MOR (psi)

		Temperature (F)				
		35	72	100	150	200
	0%	6072	5152	4750	3844	5526
MC	7%	6496	5568	5426	4686	4176

Table 5.5 PF-MOR Analysis of Variance Report

ANOVA Table for Response Variable: MOR

Source	DF	Sum-Squares	Mean Square	F-Ratio	
T	4	18796380	4699095	4.23	**
LR	1	16104169	16104169	14.49	**
LOF	3	2692211	897404	0.81	
MC	1	882	882	0.00	
T&MC	4	12179788	3044947	2.74	*
T(LR)*MC	1	6375625	6375625	5.74	*
LOF(T&MC)	3	5804163	1934721	1.74	
Error	40	44450800	1111270		
Total	49	75427850			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means of PF MOR (psi)

		Temperature (F)				
		35	72	100	150	200
	0%	5202	4188	5292	4150	4442
MC	7%	5842	5772	4406	3534	3692

Table 5.6 PLY-MOR Analysis of Variance Report

ANOVA Table for Response Variable: MOR

Source	DF	Sum-Squares	Mean Square	F-Ratio	
T	4	21988028	5497007	3.03	*
LR	1	16900321	16900321	9.33	**
LOF	3	5087707	1695902	0.94	
MC	1	334562	334562	0.18	
T&MC	4	8415308	2103827	1.16	
T(LR)*MC	1	4247721	4247721	2.34	
LOF(T&MC)	3	4167587	1389196	0.77	
Error	40	72480880	1812022		
Total	49	103218778			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means of PLY MOR (psi)

		Temperature (F)				
		35	72	100	150	200
	0%	6090	6268	4976	4890	5754
MC	7%	6602	6322	4894	5330	4012

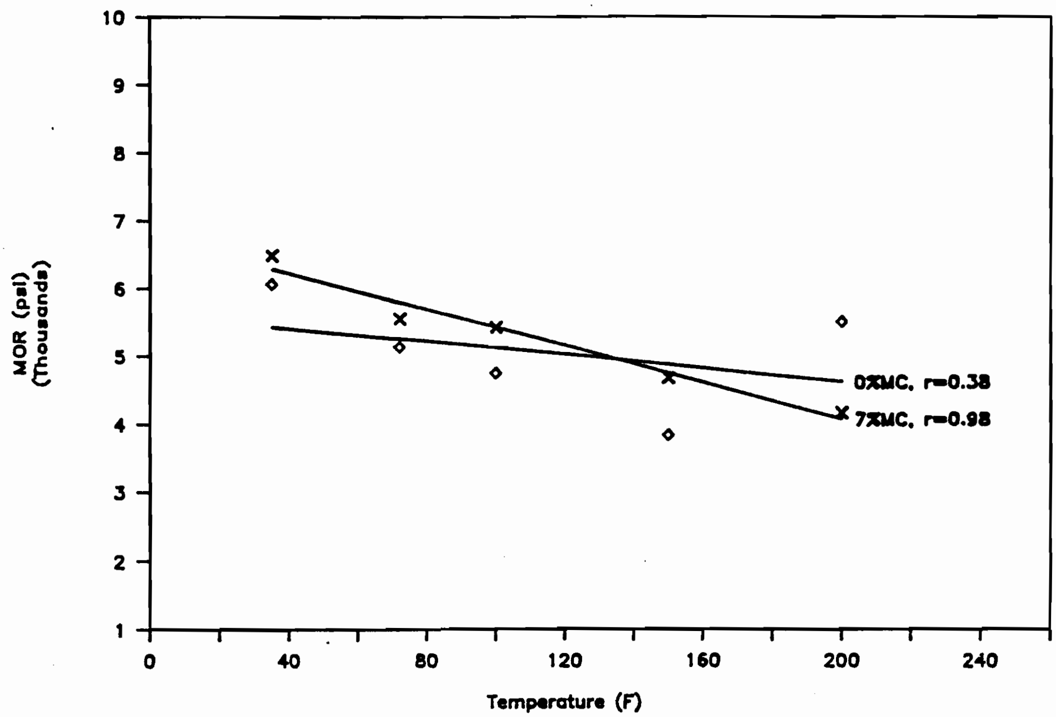

Figure 5.5 Mean of MOR (ISO)

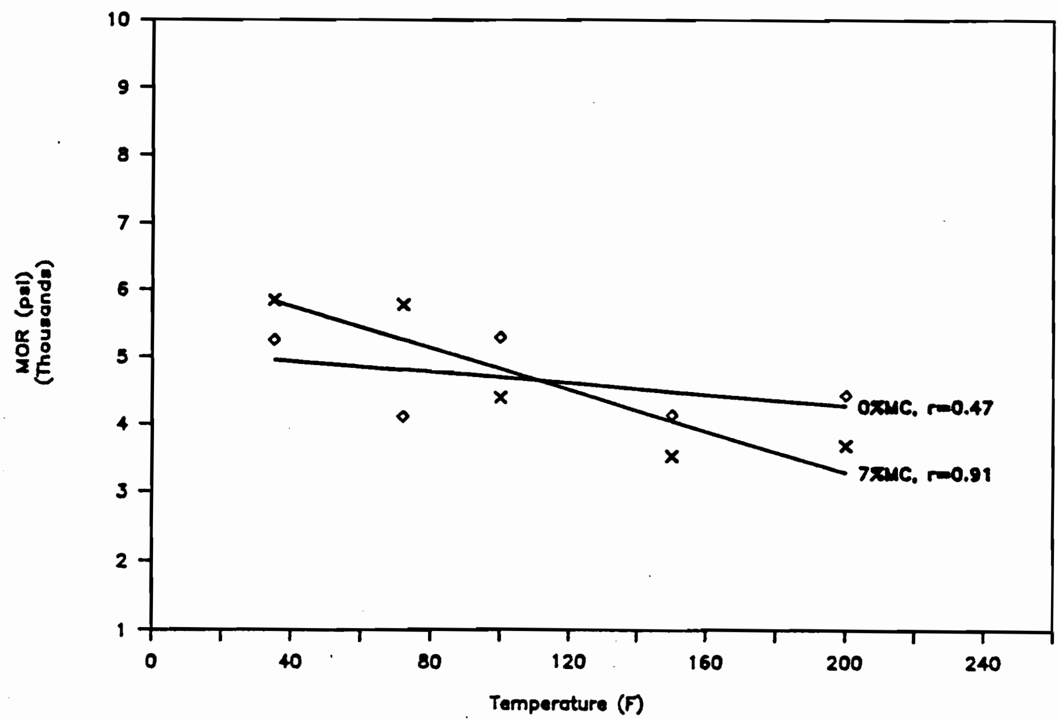

Figure 5.6 Mean of MOR (PF)

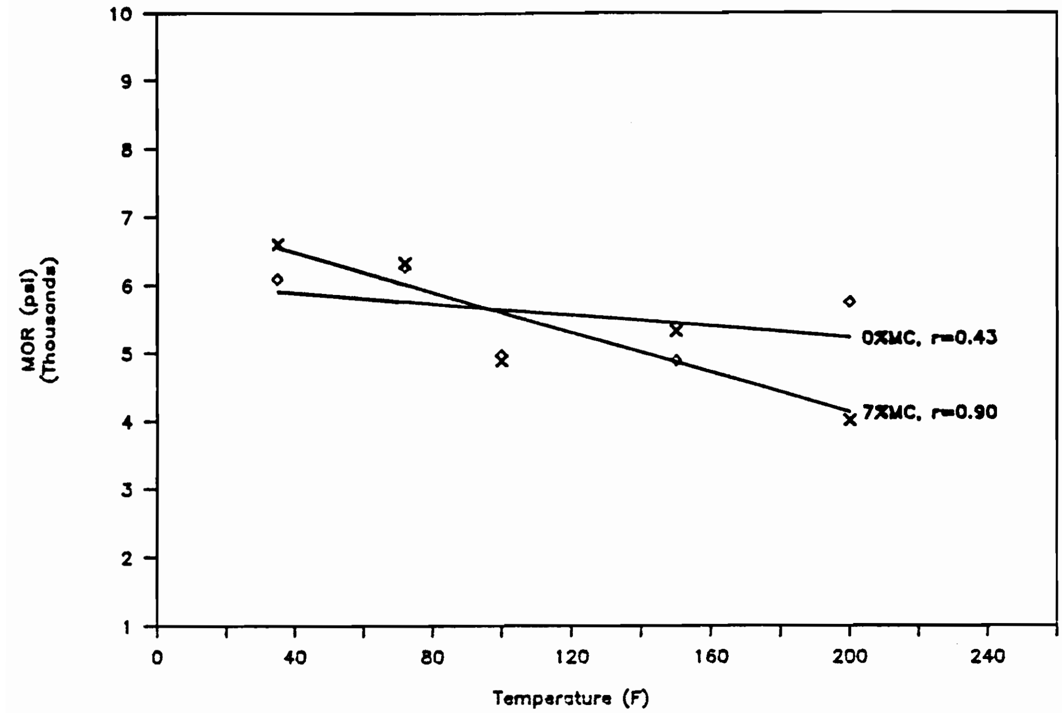

Figure 5.7 Mean of MOR (PLY)

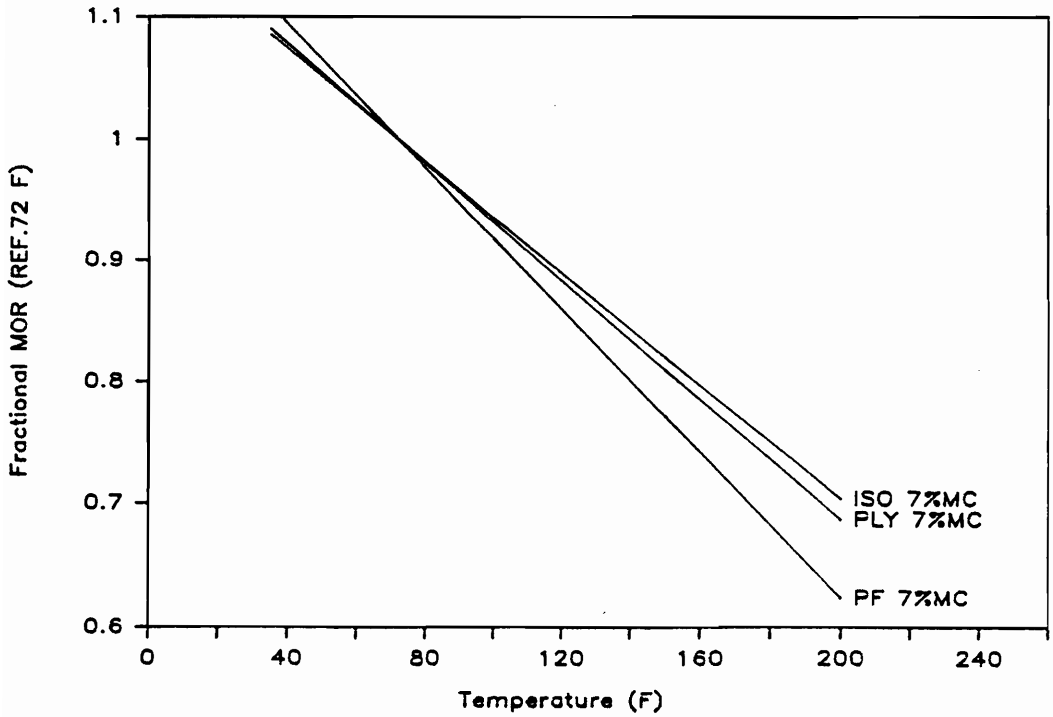

Figure 5.8 MOR at 7%MC

The test of the slope of regression line for effect of temperature on MOR was similar to the slope regarding temperature effect on MOE. The linear relationship between MOR and temperature was significant at level 0.01 for both PF-OSB and plywood, and at level 0.05 for ISO-OSB at 7% moisture content and was not significant for all three panel types at 0% moisture content (see Tables B7 through B12 in Appendix).

Again, normalizing the data for a MOR of 1.0 at 72 °F and plotting the resulting values gives a composite graph for MOR versus temperature in Figure 5.8. The modulus of rupture at a constant moisture content decreases linearly with an increase in temperature as given by the relation

$$R_{t1}=R_{t2}-dr(t_1-t_2) \qquad [5.3]$$

where R_{t1} is modulus of rupture at seven percent moisture content and t_1 °F and dr is the modulus of regression coefficient of modulus of rupture on temperature. Equation [5.3] is valid in the range 35 to 200 °F, the strength temperature coefficients, dr, is proportional to strength at 72 °F and is given by

dr=0.0023 (ISO & PLY)

dr=0.00293 (PF)

The reduction of modulus of elasticity and modulus of rupture for all three panel types was close, so equations [5.2] and [5.3] may be represented

$$S_{t1}= S_{t2}-ds\ (t_1-t_2) \qquad [5.4]$$

where S_{t1} is strength MOE or MOR at t_1 °F, strength S_{t2} at temperature t_2 °F is related to strength S_{t1} at temperature t_1. The Figure 5.9 showed the relationship between MOE and MOR in this study.

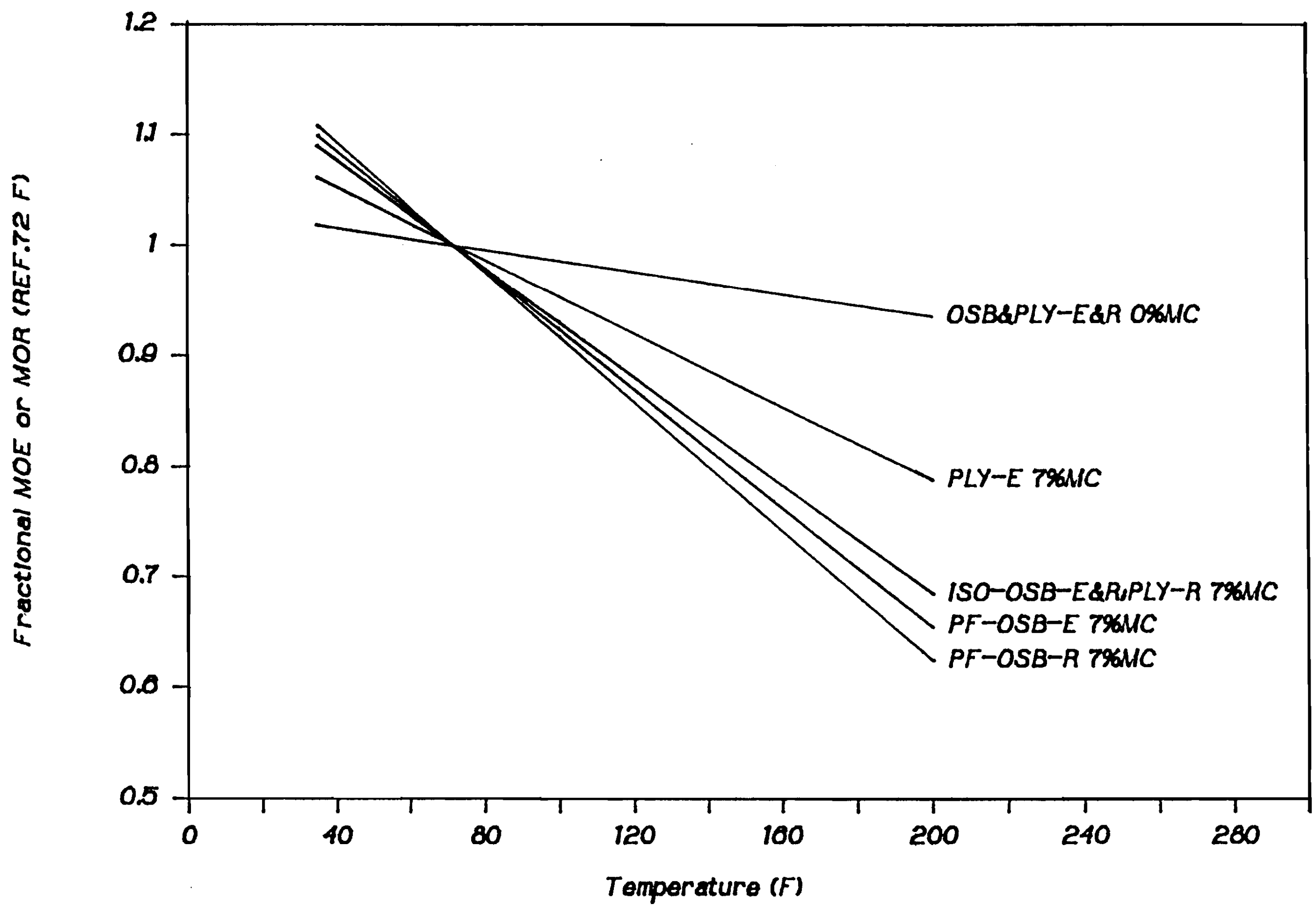

Figure 5.9 Effect of temperature on MOE and MOR of three type panels
E-MOE, R-MOR, ER-MOE and MOR

VI. DISCUSSION AND CONCLUSION

Comparisons of these results for plywood and OSB can be made to those in the literature for solid wood and particleboard at similar moisture contents. As shown in Figure 6.1, all panel types tested for MOE at 0% moisture content agreed closely with the test values recorded by Sulzberger (1953) for solid wood. Whereas, for MOE measurements at 7% moisture content only the plywood agreed with Sulzberger's data for solid wood at 8%. The MOE values for both OSB type panels at 7% moisture content decreased faster than those of the solid wood.

Interestingly, the ranking of the MOR results in comparison to the same literature differed, see Figure 6.2. For the OSB and plywood at 0% moisture content there was no significant change in MOR with temperature; however, Sulzberger showed for his data that solid wood had a significant decrease in strength with increase in temperature. At 7% moisture content the literature tended to agree better with the experimental results obtained for the OSB and the plywood. However, the MOR decrease rate appeared to be greater for the phenolic bonded OSB than the other panel types tested or as given by the literature.

Conclusions for the range of the study parameters were:

1. when panels were oven-dry (0% moisture content) there were no statistically significant correlations of either

modulus of rupture or modulus of elasticity with change in temperature. 2. when the panels were tested at 7% moisture content there were a significant decreases in both MOR and MOE with an increase in temperature. For example, when panel temperature was increased from 72 to 200°F there was an approximate decrease for MOR of 30% for both the plywood and the isocyanate bonded OSB and 40% for the phenolic bonded OSB, whereas for MOE there was a decrease of 20% for plywood, 30% for the isocyanate bonded OSB, and 35% for the phenolic bonded OSB.

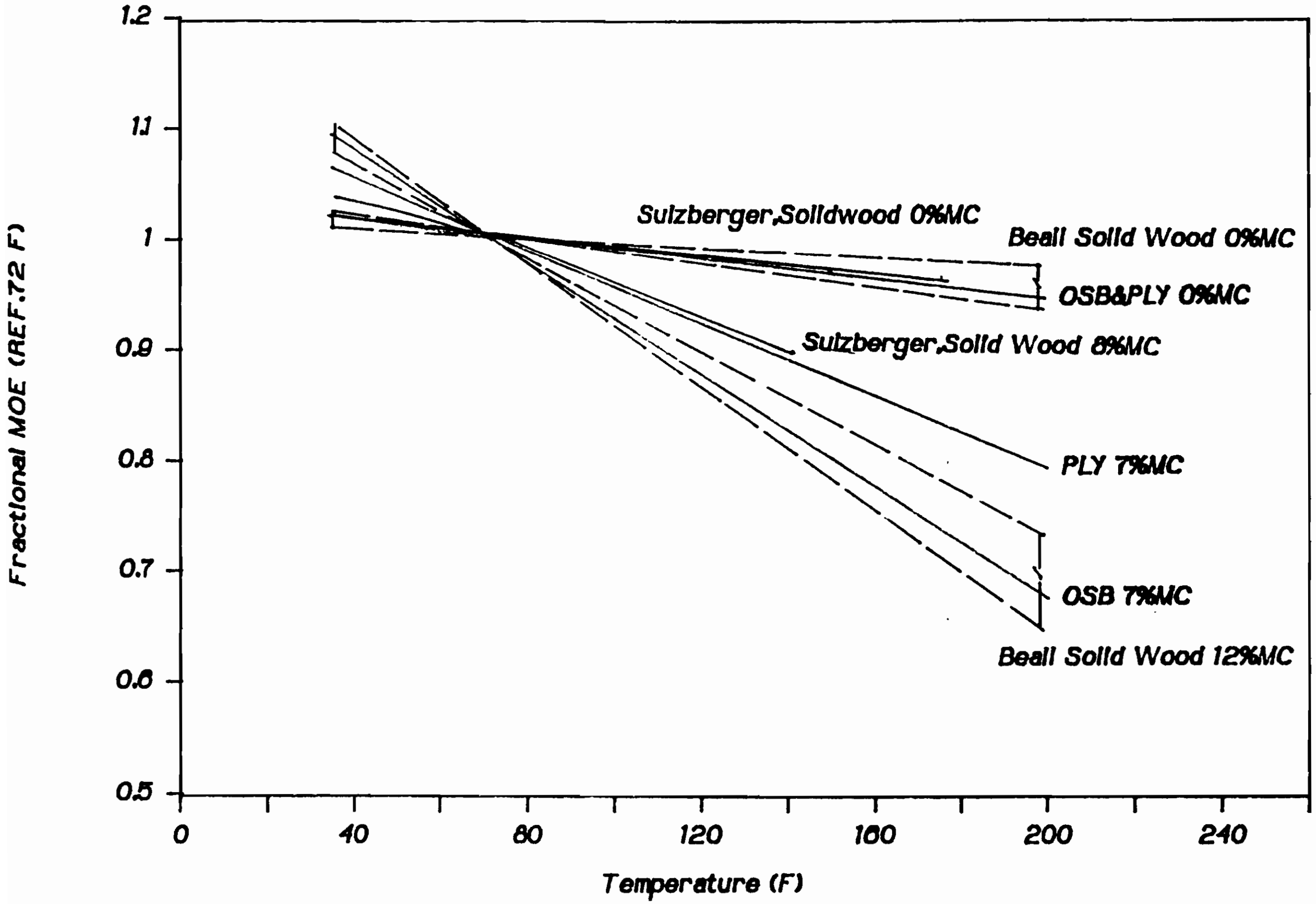

Figure 6.1 Effect of temperature on MOE in static bending

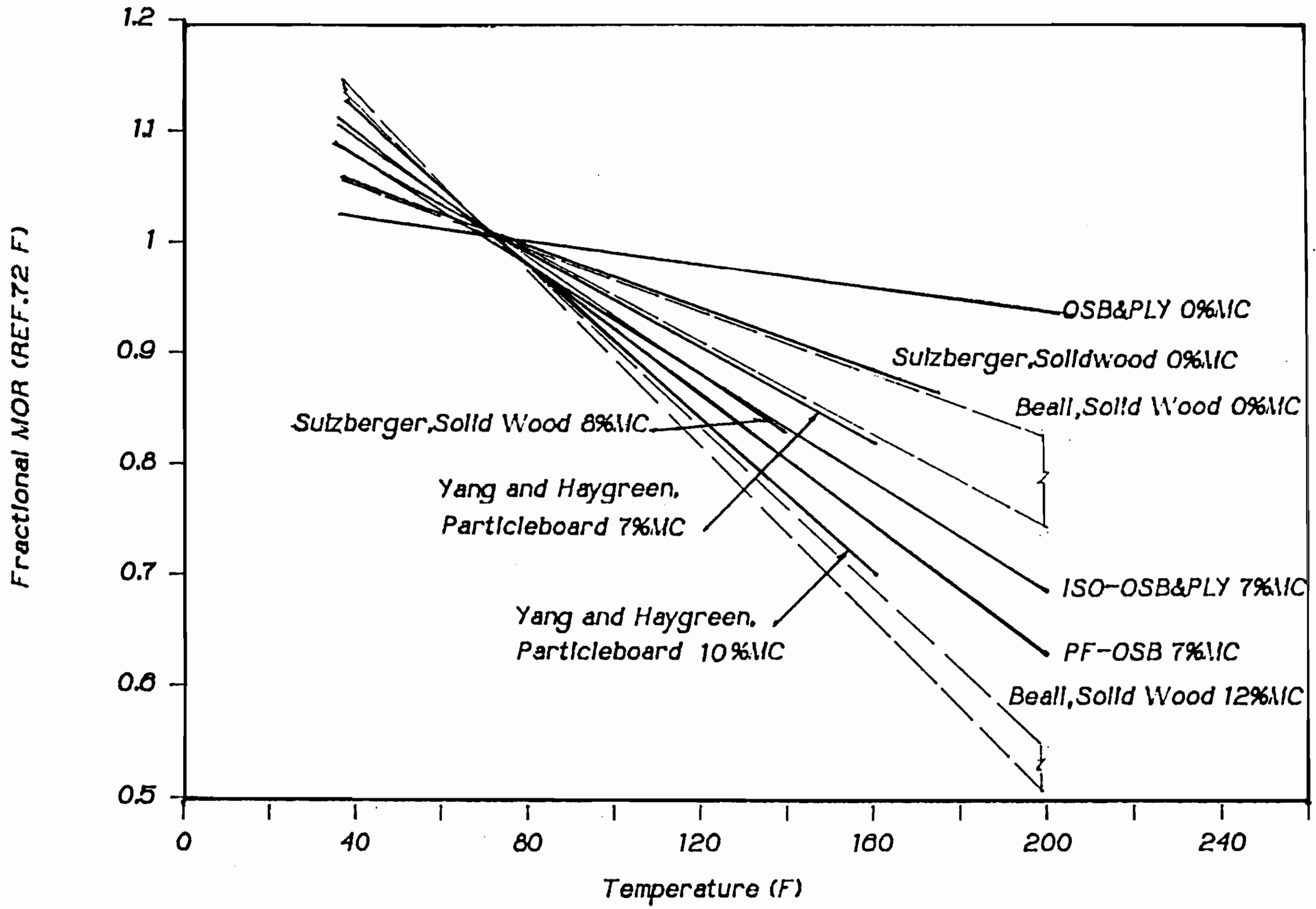

Figure 6.2 Effect of temperature on MOR in static bending

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APPENDICES

Table A1 ISO-MOE 0%MC Analysis of Variance Report

ANOVA Table for Response Variables
M1T1,M1T2,M1T3,M1T4,M1T5

Source	DF	Sum-Squares	Mean Square	F-Ratio
Temp.	4	11.74E10	2.94E10	1.33
LR	1	0.01E10	0.01E10	0.004
LOF	3	11.74E10	3.91E10	1.772
ERROR	20	44.14E10	2.21E10	
TOTAL(Adj)	24	55.88E10		

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	923439		923439.2
M1T1	5	993388	66437.42	69948.81
M1T2	5	876732	66437.42	-46707.19
M1T3	5	886856	66437.42	-36583.19
M1T4		1016658	66437.42	93218.81

Table A2 ISO-MOE 7%MC Analysis of Variance Report

ANOVA Table for Response Variables
M2&T1,M2&T2,M2&T3,M2&T4,M2&T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	53.03E10	13.26E10	10.11	**
LR	1	51.10E11	51.10E10	38.98	**
LOF	3	1.93E10	0.64E10	0.49	
ERROR	20	26.23E10	13.11E10		
TOTAL(Adj)	24	79.26E10			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	896593		896592.8
M2&T1	5	1124032	51210.98	227439.2
M2&T2	5	993624	51210.98	97031.2
M2&T3	5	866948	51210.98	-29644.8
M2&T4	5	766176	51210.98	-130416.8
M2&T5	5	732184	51210.98	-164408.8

Table A3 PF-MOE 0%MC Analysis of Variance Report

ANOVA Table for Response Variables
M1&T1,M1&T2,M1&T3,M1&T4,M1&T5

Source	DF	Sum-Squares	Mean Square	F-Ratio
Temp.	4	4.24E10	1.06E10	0.47
LR	1	2.42E10	2.42E10	1.07
LOF	3	1.82E10	0.61E10	0.27
ERROR	20	45.27E10	2.26E10	
TOTAL(Adj)	24	49.51E10		

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	824682		824682.4
M1&T1	5	887640	67282.35	62957.6
M1&T2	5	820600	67282.35	-4082.4
M1&T3	5	845354	67282.35	20671.6
M1&T4	5	763648	67282.35	-61034.4
M1&T5	5	806170	67282.35	-18512.4

Table A4 PF-MOE 7%MC Analysis of Variance Report

ANOVA Table for Response Variables
M2&T1,M2&T2,M2&T3,M2&T4,M2&T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	53.78E10	13.45E10	13.12	**
LR	1	47.10E10	47.10E10	45.95	**
LOF	3	6.68E10	2.23E10	2.17	
ERROR	20	20.49E10	1.02E10		
TOTAL(Adj)	24	7.43E11			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	766338		766337.6
M2&T1	5	924602	45269.44	158264.4
M2&T2	5	949176	45269.44	182838.4
M2&T3	5	735214	45269.44	-31123.6
M2&T4	5	617342	45269.44	-148995.6
M2&T5	5	605354	45269.44	-160983.6

Table A5 PLY-MOE 0%MC Analysis of Variance Report

ANOVA Table for Response Variables
M1&T1,M1&T2,M1&T3,M1&T4,M1&T5

Source	DF	Sum-Squares	Mean Square	F-Ratio
Temp.	4	0.27E10	0.07E10	0.05
LR	1	0.03E10	0.03E10	0.025
LOF	3	0.24E10	0.08E10	0.054
ERROR	20	26.62E10	1.33E10	
TOTAL(Adj)	24	26.89E10		

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	1081688		1081688
M1&T1	5	1067928	51592.36	-13759.6
M1&T2	5	1088180	51592.36	6492.4
M1&T3	5	1097284	51592.36	15596.4
M1&T4	5	1081468	51592.36	-219.6
M1&T5	5	1073578	51592.36	-8109.6

Table A6 PLY-MOE 7%MC Analysis of Variance Report

ANOVA Table for Response Variables
M2T1,M2T2,M2T3,M2T4,M2T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	32.44E10	8.11E10	4.42	*
LR	1	2.66E10	2.66E10	14.49	**
LOF	3	5.84E10	1.95E10	1.06	
ERROR	20	36.73E10	1.84E10		
TOTAL(Adj)	24	69.17E10			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	1038463		1038463
M2T1	5	1133280	60605.83	94817.2
M2T2	5	1132020	60605.83	93557.2
M2T3	5	1086034	60605.83	47571.2
M2T4	5	1012812	60605.83	-25650.8
M2T5	5	828168	60605.83	-210294.8

Table A7 ISO-MOR 0%MC Analysis of Variance Report

ANOVA Table for Response Variables
M1T1,M1T2,M1T3,M1T4,M1T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	1.45E07	0.36E07	1.70	
LR	1	0.29E07	0.29E07	1.35	
LOF	3	1.16E07	0.39E07	1.82	
ERROR	20	4.28E07	0.21E07		
TOTAL(Adj)	24	5.73E07			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	5077		5076.8
M1T1	5	6112	654.0275	1035.2
M1T2	5	5152	654.0275	75.2
M1T3	5	4750	654.0275	-326.8
M1T4	5	3844	654.0275	-1232.8
M1T5	5	5526	654.0275	449.2

Table A8 ISO-MOR 7%MC Analysis of Variance Report

ANOVA Table for Response Variables
M2T1,M2T2,M2T3,M2T4,M2T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	1.58E07	0.39E07	3.86	*
LR	1	1.53E07	1.53E07	14.94	**
LOF	3	0.05E07	0.02E07	0.17	
ERROR	20	2.04E07	0.10E07		
TOTAL(Adj)	24	3.62E07			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	5270		5270.4
M2T1	5	6496	451.8358	1225.6
M2T2	5	5568	451.8358	297.6
M2T3	5	5426	451.8358	155.6
M2T4	5	4686	451.8358	-584.4
M2T5	5	4176	451.8358	-1094.4

Table A9 PF-MOR 0%MC Analysis of Variance Report

ANOVA Table for Response Variables
M1T1,M1T2,M1T3,M1T4,M1T5

Source	DF	Sum-Squares	Mean Square	F-Ratio
Temp.	4	6463664	1615916	1.03
LR	1	1107072	1107072	0.71
LOF	3	5356592	1785531	1.14
ERROR	20	3.14E07	1567516	
TOTAL(Adj)	24	3.78E07		

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	4641		4640.8
M1T1	5	5202	559.9136	561.2
M1T2	5	4118	559.9136	-522.8
M1T3	5	5292	559.9136	651.2
M1T4	5	4150	559.9136	-490.8
M1T5	5	4442	559.9136	-198.8

Table A10 PF-MOR 7%MC Analysis of Variance Report

ANOVA Table for Response Variables
M2T1,M2T2,M2T3,M2T4,M2T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	2.45E07	0.61E07	9.36	**
LR	1	2.14E07	2.14E07	32.63	**
LOF	3	0.31E07	0.10E07	1.60	
ERROR	20	1.31E07	0.06E07		
TOTAL(Adj)	24	3.76E07			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	4649		4649.2
M2T1	5	5842	361.9459	1192.8
M2T2	5	5772	361.9459	1122.8
M2T3	5	4406	361.9459	-243.2
M2T4	5	3534	361.9459	-1115.2
M2T5	5	3692	361.9459	-957.2

Table A11 PLY-MOR 0%MC Analysis of Variance Report

ANOVA Table for Response Variables
M1&T1,M1&T2,M1&T3,M1&T4,M1&T5

Source	DF	Sum-Squares	Mean Square	F-Ratio
Temp.	4	8017096	2004274	0.84
LR	1	2101250	2101250	0.88
LOF	3	5915846	1971949	0.83
ERROR	20	4.76E07	2377556	
TOTAL(Adj)	24	5.56E07		

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	5596		5595.6
M1&T1	5	6090	689.5732	494.4
M1&T2	5	6268	689.5732	672.4
M1&T3	5	4976	689.5732	-619.6
M1&T4	5	4890	689.5732	-705.6
M1&T5	5	5754	689.5732	158.4

Table A12 PLY-MOR 7%MC Analysis of Variance Report

ANOVA Table for Response Variables
M2T1,M2T2,M2T3,M2T4,M2T5

Source	DF	Sum-Squares	Mean Square	F-Ratio	
Temp.	4	2.24E07	0.56E07	4.49	**
LR	1	1.90E07	1.90E07	15.28	**
LOF	3	0.33E07	0.11E07	0.89	
ERROR	20	2.49E07	1246488		
TOTAL(Adj)	24	4.73E07			

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Means & Effects

Term	Count	Mean	Std.Error	Effect
ALL	25	5432		5432
M2T1	5	6602	499.2971	1170
M2T2	5	6322	499.2971	890
M2T3	5	4894	499.2971	-538
M2T4	5	5330	499.2971	-102
M2T5	5	4012	499.2971	-1420

* Significant at the 5% level of probability
** Significant at the 1% level of probability

Table B1 ISOMOE-0 Regression Output:

Constant	909634.7	
Std Err of Y Est	87984.76	
R Squared	0.011024	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	123.9174	
Std Err of Coef.	677.6243	
t critical value	0.22	

Table B2 ISOMOE-7 Regression Output:

Constant	1163953.	
Std Err of Y Est	54625.89	
R Squared	0.915596	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-2400.00	
Std Err of Coef.	420.7073	
t critical value	-4.26	**

Table B3 PFMOE-0 Regression Output:

Constant	883364.4	
Std Err of Y Est	35577.94	
R Squared	0.551961	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-526.768	
Std Err of Coef.	274.0074	
t critical value	-1.15	

Table B4 PFMOE-7 Regression Output:

Constant	1023738.	
Std Err of Y Est	76491.34	
R Squared	0.836811	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-2310.59	
Std Err of Coef.	589.1064	
t critical value	-5.02	**

Table B5 PLYMOE-0 Regression Output:

Constant	1082410.	
Std Err of Y Est	13414.29	
R Squared	0.001312	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-6.48626	
Std Err of Coef.	386.0465	
t critical value	-0.02	

Table B6 PLYMOE-7 Regression Output:

Constant	1243926.	
Std Err of Y Est	50125.44	
R Squared	0.883835	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-1844.37	
Std Err of Coef.	386.0465	
t critical value	-6.50	**

Table B7 ISOMOR-0 Regression Output:

Constant	5619.480	
Std Err of Y Est	893.4768	
R Squared	0.148411	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-4.97558	
Std Err of Coef.	6.881210	
t critical value	-1.00	

Table B8 ISOMOR-7 Regression Output:

Constant	6768.072	
Std Err of Y Est	188.7768	
R Squared	0.966104	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-13.4441	
Std Err of Coef.	1.453885	
t critical value	-2.70	*

Table B9 PFMOR-0 Regression Output:

Constant	5116.682	
Std Err of Y Est	594.9300	
R Squared	0.216755	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-4.17488	
Std Err of Coef.	4.581918	
t critical value	-0.95	

Table B10 PFMOR-7 Regression Output:

Constant	6370.169	
Std Err of Y Est	541.2690	
R Squared	0.820720	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-15.4485	
Std Err of Coef.	4.168643	
t critical value	-3.53	**

Table B11 PLYMOR-0 Regression Output:

Constant	6060.800	
Std Err of Y Est	660.6609	
R Squared	0.183358	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-4.17595	
Std Err of Coef.	5.088153	
t critical value	-0.91	

Table B12 PLYMOR-7 Regression Output:

Constant	7071.164	
Std Err of Y Est	525.0686	
R Squared	0.815667	
No. of Observations	5	
Degrees of Freedom	3	
X Coefficient(s)	-14.7142	
Std Err of Coef.	4.043873	
t critical value	-3.20	**