

The Effect of Exposure in Elevated Temperatures on Bending Properties of Wood^{*1}

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ABSTRACT

Temperature has important effect on mechanical properties of wood. These effect needs to be understood and taken into account in the structural use of wood. Furthermore, the effect of cooling after exposing to high temperature must be explained.

In this study, the effect of temperature, exposure time, specific gravity, and cooling on bending properties were investigated.

The boundary temperatures at which bending MOE and MOR reduced rapidly were approximately 20 0℃ and 150℃, respectively. This boundary temperature was nearly constant with independence of species(specific gravity), exposure time, and cooling. Above the boundary temperature, the effect of exposure time was increased with temperature and the reduction of bending MOE and MOR for Japanese Larch with relatively higher specific gravity was smaller than that of Hem-fir. The recovery of bending MOE and MOR after cooling was also more significant above the boundary temperature than below. The degree of cooling effect was larger for MOR than MOE.

Consequently, bending properties of wood in elevated temperatures should be considered in terms of the boundary temperature, 200℃ for bending MOE, 150℃ for MOR, and these boundary temperatures must be considered an important factor. Furthermore, to evaluate the safety of structure, the recovery after cooling should be considered.

Key words : Boundary Temperature, Bending MOE, Bending MOR, Cooling

INTRODUCTION

One of the important factors to evaluate the structural safety in wood, is fire endurance. Fire endurance is the ability to maintain structural integrity when exposed to fire, and

is especially important in wood structures. In general, endurance time, which is the interval between an outbreak of fire and destruction of structures, is used to estimate the fire endurance capacity of structures in many countries.

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Fire endurance has been studied with the knowledge of the relationship between temperature and mechanical properties of wood. Many researches have been accomplished on the strength and stiffness of wood members exposed to elevated temperatures. However, there is few published information available on the effect of cooling. To reevaluate the safety of structures, many factors have to be considered such as species, temperature, exposure time, and cooling effect.

Many studies on the tensile strength in elevated temperatures have been accomplished. Schaffer (1971) studied about tensile strength parallel to grain with oven dried specimens. The results were that tensile strength decreased slowly with temperature up to 200°C (the strength at 150°C was 85% of that in room temperature.), but decreased rapidly above 200°C. Knudson *et al.* (1974) tested Douglas fir with 12% moisture content (M.C.) and developed a linear regression equation between temperatures and relative tensile strength.

Parl *et al.* (1977) studied about the relationship between temperature and bending properties. They found out that there was the linear relation between temperature and bending properties in temperature of -35°C ~ 75°C, and M.C. of 0%, 15%, 75%.

The relationship between temperature and modulus of elasticity (MOE) has also been studied. Preusser (1968) reported that temperature levels should be divided into three specifications according to the change of bending MOE. Up to 160°C, MOE was maintained about 90% of that in room temperature. From 160°C to 180°C, MOE was decreased slowly. Over 180°C, MOE was decreased significantly. Because this test included preheating process, and the cross section of specimens was larger than that in other tests, the reduction slopes of this test were smaller than that of other tests. Kim *et al.* (1994) estimated that reduction slope of MOE for Douglas fir with 15% M.C. was $-0.0044/^{\circ}\text{C}$.

Green and Evans (1994) studied about strength recovery in cooling after exposure to the elevated temperatures and reported that the strength of wood which was heated up to 100°C, was recovered completely after cooling and that strength reduction was related with chemical and physical properties of wood with reference to Schaffer's result (1971).

In this study, the relationships between factors such as temperature, species, exposure time, and cooling and bending properties of wood were discussed. Furthermore, the boundary temperature at which bending properties would change rapidly was focused on.

MATERIALS & METHODS

Specimens were prepared from air-dried Hem-fir (*Tsuga heterophylla*) and Japanese Larch (*Larix leptolepis*) lumber with specific gravity of 0.36 and 0.54, respectively. In order to reduce effects of temperature gradient and to heat the entire section in as short a time as possible, all specimens were prepared with 10-mm-square cross section. Static bending specimens conformed to ASTM D 143 specifications except for the reduction in cross section.

Specimens were tested at temperatures of 50, 100, 125, 150, 175, 200, 225, and 250°C. Prior to elevated temperature exposure, 30 randomly selected specimens were used for measuring the time for the entire section to reach the target temperature with thermocouples and automatic temperature recorder.

As shown in Fig. 1, three holes with diameter and depth of 2mm and 6mm respectively, were made on each specimen for thermocouples. The locations of holes were 1/4, center, and 3/4 point along the longitudinal direction. Holes were filled up with silicon, and thermocouples were connected to the automatic temperature recorder. Specimens were exposed to the appointed temperature (50,

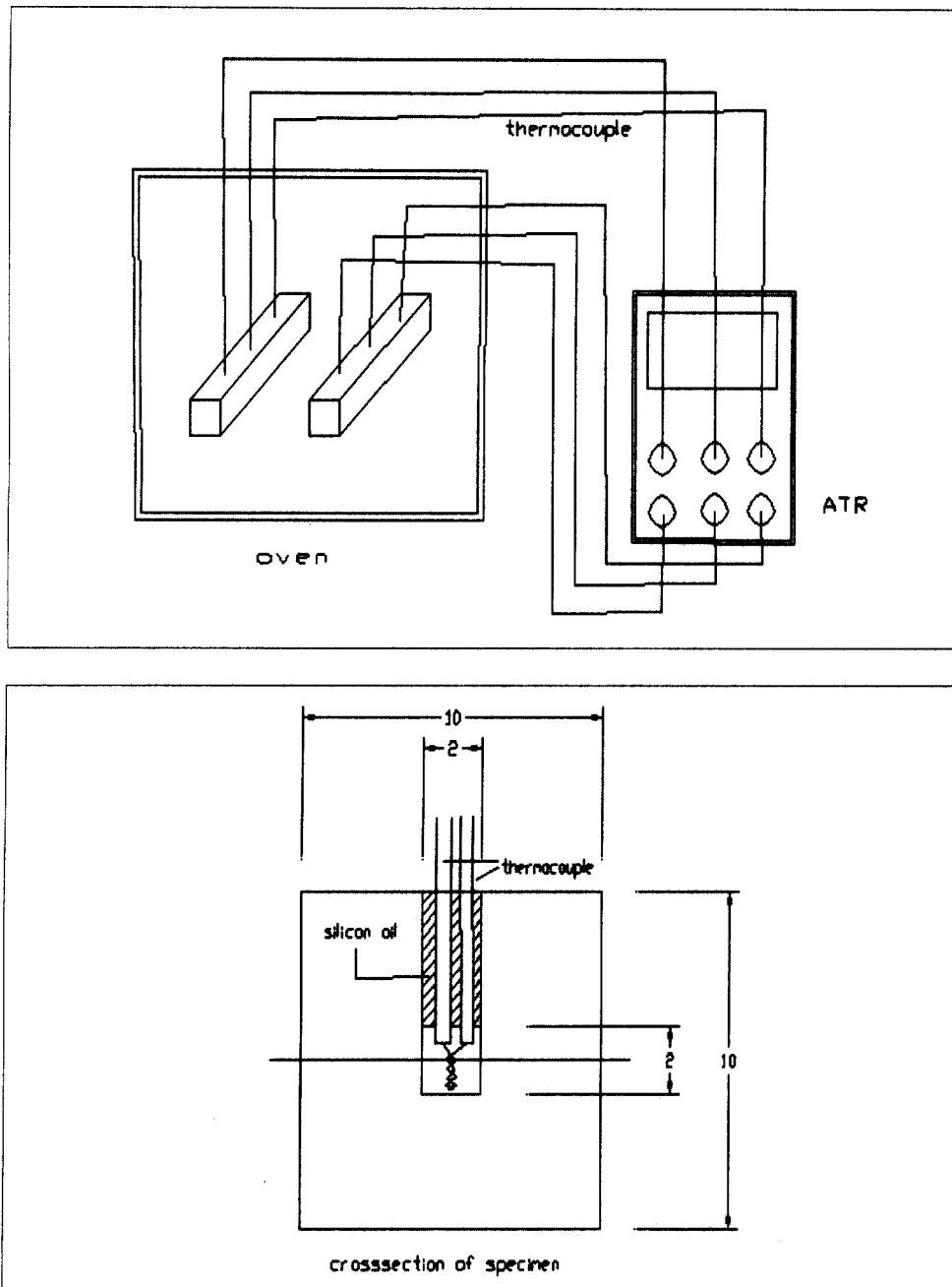


Fig. 1. The equipment of the test for measuring the time to reach the target temperatures.

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100, and 150°C) in the oven. The heating was continued until thermocouples reached the target temperature levels. Measured values were linearly increased with temperature independent of species and the longitudinal position of thermocouples.

All specimens were equilibrated to 12% M.C. for 2 months, and nondestructive bending tests for initial bending MOE were made.

Except for controls, specimens were heated in an oven for 0, 1, and 2 hours (additive exposure time after reach the target temperature) at each temperature level and tested either hot or after cooling for 48 hours under 12% EMC and room temperature conditions to determine the effect of temperature, time, and cooling on bending properties.

RESULTS & DISCUSSION

To investigate the effect of temperature, exposure time, and cooling on bending properties for two species, the relative MOE and MOR were

estimated and presented in Fig. 2~9. Relative MOE was calculated by dividing MOE at a given temperature with initial MOE measured by nondestructive bending test, while relative MOR was calculated by dividing MOR at a given temperature with the mean value of MOR at the room temperature.

Effect of temperature and exposure time

The relationships between temperature and bending MOE of Hem-fir and Japanese Larch for each exposure time was shown in Fig. 2 and 3. Relative bending MOE of Hem-fir decreased slowly with temperature independent of exposure time until approximately 90% of initial bending MOE remained at 200°C. The effect of exposure time was never shown for both species. However, above 200°C, the reduction was somewhat increased and the effect of exposure time was also increased. Specimens, for example, exposed at 250°C for 2 hours lost nearly 60% of initial bending MOE. In Fig. 3, Compared with the result of Hem-fir, the tendency was similar except that the reduction was relatively small above 200°C.

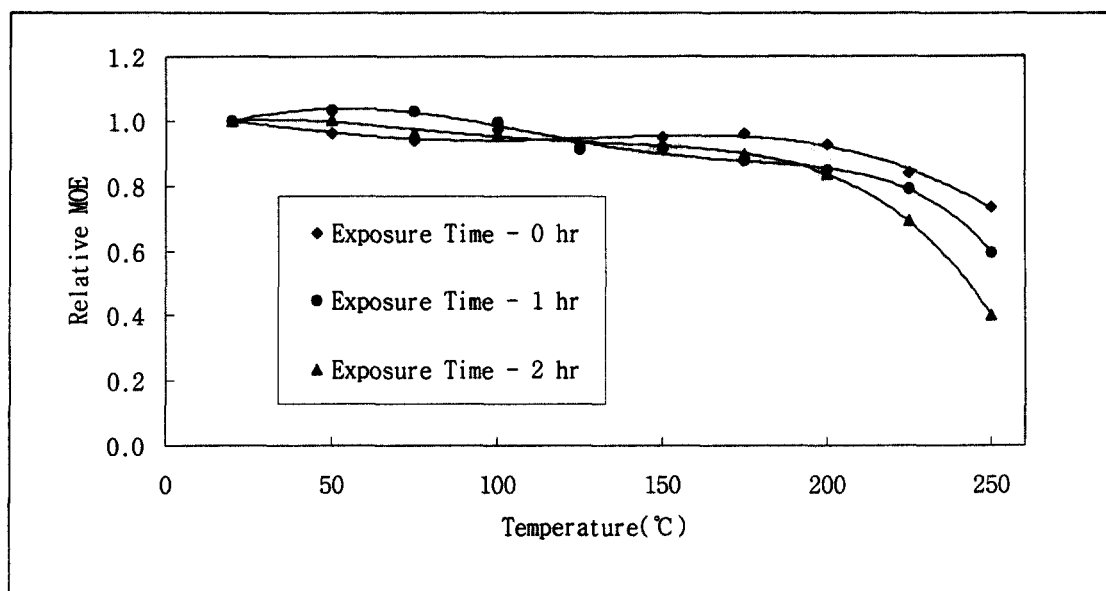


Fig. 2. The reduction of relative MOE in elevated temperatures for Hem-fir without cooling.

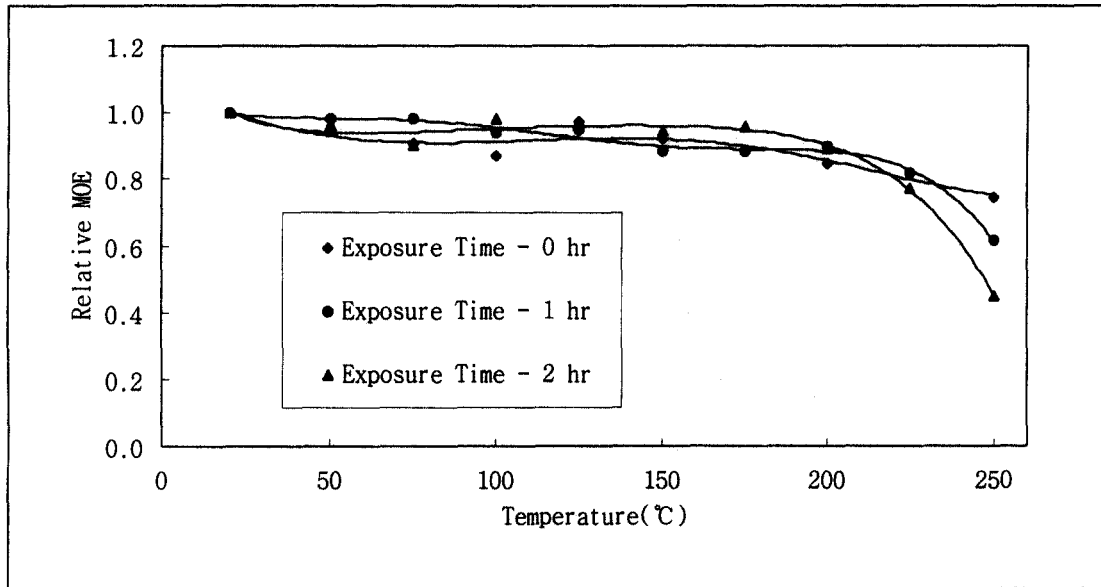


Fig. 3. The reduction of relative MOE in elevated temperatures for Larch without cooling.

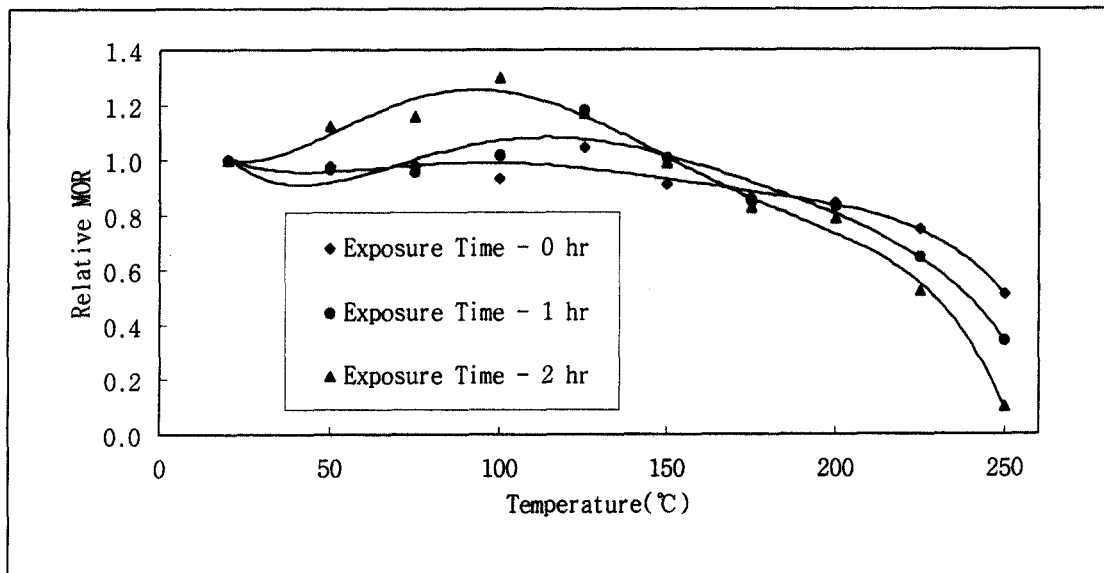


Fig. 4. The reduction of relative MOR in elevated temperatures for Hem-fir without cooling.

The effect of temperature and exposure time on bending MOR for two species was indicated in Fig. 4 and 5 respectively. There were three different tendencies in reduction of bending MOR

with temperature, compared with that of bending MOE shown in Fig. 2 and 3. First, the boundary temperature at which bending MOR decreased rapidly was approximately 150°C, while 200°C for

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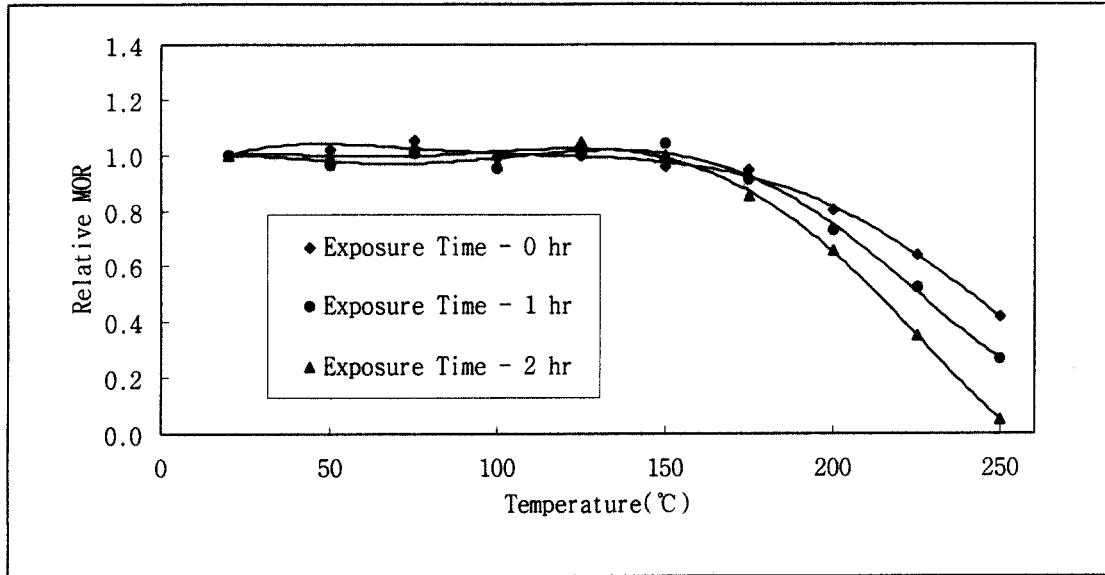


Fig. 5. The reduction of relative MOR in elevated temperatures for Larch without cooling.

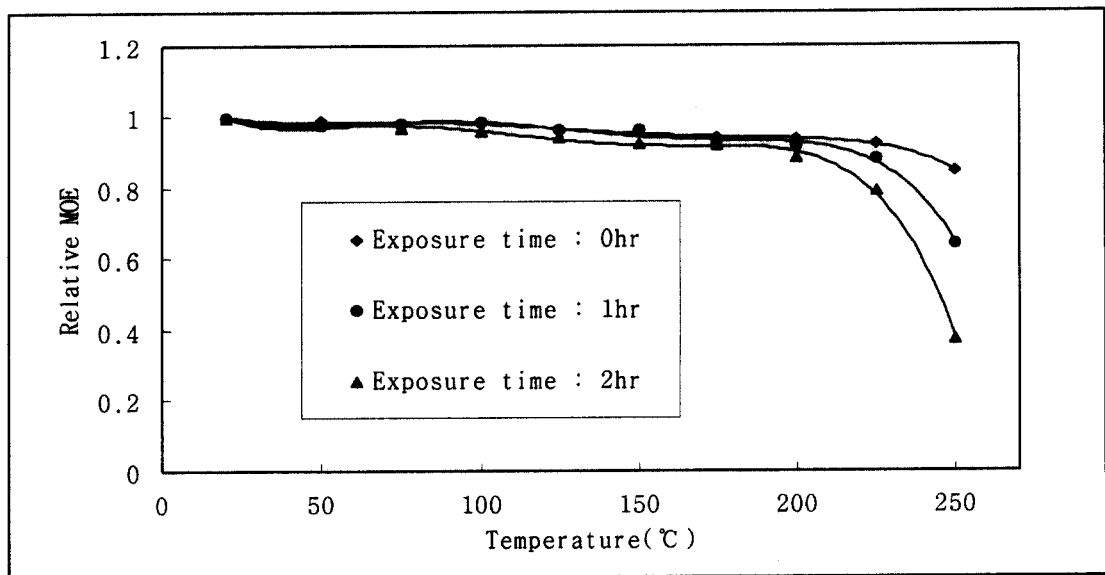


Fig. 6. The reduction of relative MOE in elevated temperatures for Hem-fir after cooling.

MOE. This result was associated with the thermal degradation of wood components, especially softening of lignin. Schaffer(1971) insisted that lignin started to degrade above 120°C and the degrad-

ation was accelerated above 200°C. From these results, MOR was affected more significantly by degradation or softening of lignin than MOE. The second different tendency was that above

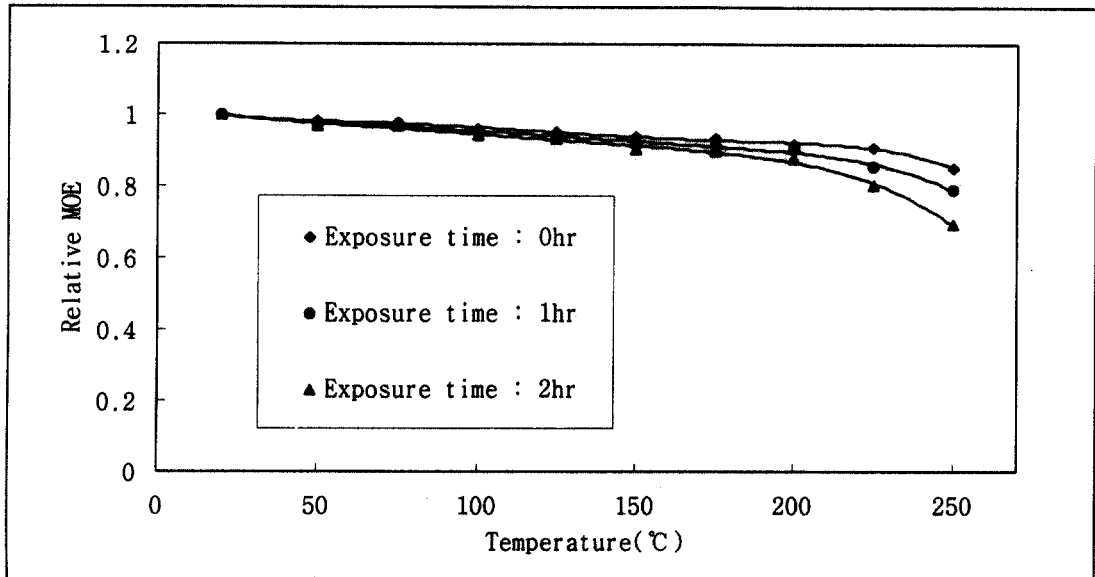


Fig. 7. The reduction of relative MOE in elevated temperatures for Larch after cooling.

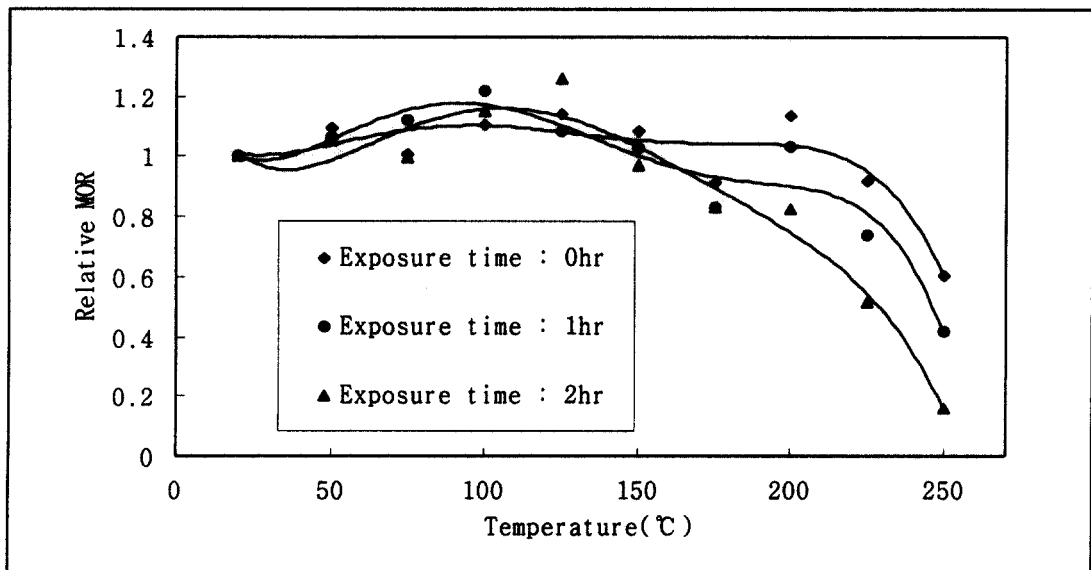


Fig. 8. The reduction of relative MOR in elevated temperatures for Hem-fir after cooling.

boundary temperature, the amount of reduction of MOR was larger than that of MOE. For example, specimens exposed at 250°C for 2 hours lost nearly 90% of MOR at room temperature. The third different tendency was that bending

MOR somewhat increased and subsequently decreased near 100°C, which was also reported by Knudson(1974). This result may be induced by the drying effect of bound water occurred in the case that M.C. of specimens was 12% or

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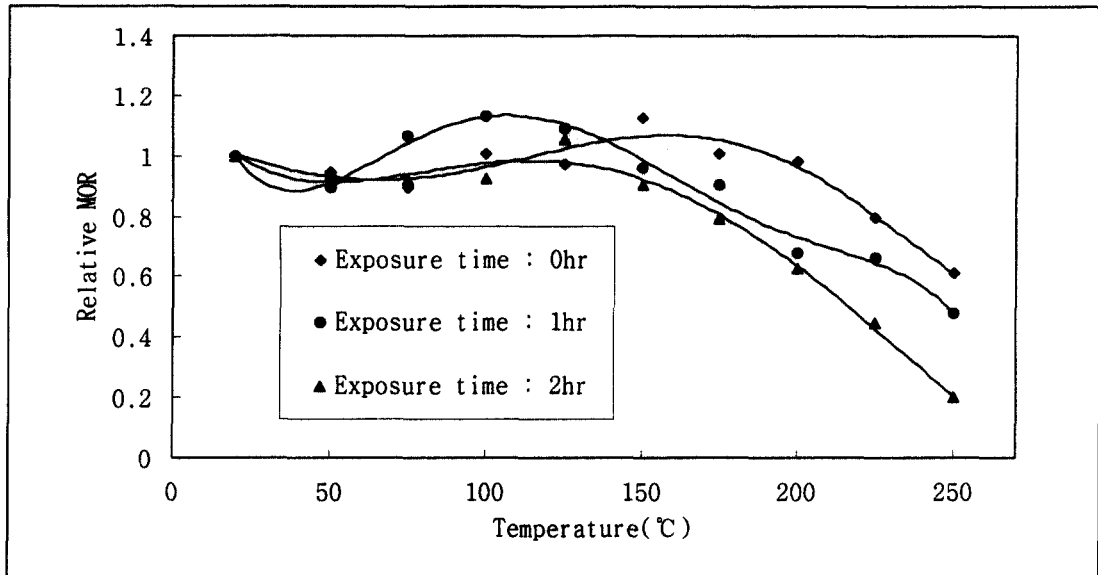


Fig. 9. The reduction of relative MOR in elevated temperatures for Larch after cooling.

higher and was relatively valid for MOR of Hem-fir in this study.

Effect of cooling

Specimens exposed for each exposure time at each temperature level were reconditioned by cooling for 48 hours under 20°C and 65% relative humidity conditions and tested for bending MOE and MOR. In Fig. 6 to Fig. 9, the changes of relative bending MOE and MOR for both species after 48-hour cooling were indicated respectively. In the case that the effect of exposure time was not included, cooling effect was significant with the confidence of 99% for both MOE and MOR with independence of exposure temperature and species. As shown in Fig. 6 and 7, above boundary temperature, MOEs for both species recovered into about 85% of initial MOE or more. Fig. 8 and 9 showed that cooling effect was more significant for MOR than MOE. For both species, MOR was recovered to nearly that of room temperature below boundary temperature, and was recovered 20% or more even above boundary

temperature. However, if exposure time was included, cooling effect was not valid. As exposure time was increased, cooling effect was decreased rapidly. This result may be induced by the long interval between exposure times. To investigate the relationship between exposure time and cooling effect, further researches with short interval of exposure time should be carried out in the future.

Reduction slope

In Table 1, effect of exposure time, species, and cooling on reduction slopes of bending properties with temperatures was shown. The reduction slopes were indicated for two temperature periods which were divided by boundary temperatures.

As shown in Table 1, reduction slopes were significantly different between two temperature periods with the confidence of 99%. This indicated that bending properties in elevated temperature should be divided into two temperature periods by the boundary temperature.

Table 1. The reduction slopes of bending properties with temperatures.

	Temperature (°C)	Exposure time (hr)	Without cooling		After cooling	
			Hem-fir	Larch	Hem-fir	Larch
MOE	20 ~ 200	0	-0.00040	-0.00061	-0.00035	-0.00045
		1	-0.00085	-0.00089	-0.00046	-0.00053
		2	-0.00091	-0.00041	-0.00062	-0.00069
	200 ~ 250	0	-0.00390	-0.00173	-0.00176	-0.00128
		1	-0.00503	-0.00270	-0.00556	-0.00225
		2	-0.00872	-0.00496	-0.01025	-0.00361
MOR	20 ~ 150	0	-0.00086	-0.00032	0.00107	-0.00012
		1	-0.00092	0.00033	0.00024	-0.00245
		2	-0.00120	-0.00002	-0.00133	-0.00286
	150 ~ 250	0	-0.00668	-0.00542	-0.00537	-0.00372
		1	-0.00988	-0.00778	-0.00611	-0.00203
		2	-0.01370	-0.00947	-0.00669	-0.00428

CONCLUSION

Study of fire endurance is based on the knowledge of the relationship between temperature and mechanical properties of wood. As this knowledge is increased, the fire endurance model would become more accurate. In this study, the effect of temperature, exposure time, specific gravity, and cooling on bending properties were investigated.

The boundary temperatures at which bending MOE and MOR reduced rapidly were approximately 200°C and 150°C, respectively. This boundary temperature was nearly constant with independence of species (specific gravity), exposure time, and cooling.

Below the boundary temperature, the effect of exposure time and species on bending properties with temperature was not found out.

Above the boundary temperature, the effect of exposure time was increased with temperature and the reduction of bending MOE and MOR for Japanese Larch with relatively higher specific gravity was smaller than that of Hem-fir.

The recovery of bending MOE and MOR after cooling was also more significant above the boundary temperature than below. The degree of cooling effect was larger for MOR than MOE.

From the results of this study, bending properties of wood in elevated temperatures should be considered in terms of the boundary temperature, 200°C for bending MOE, 150°C for MOR, and these boundary temperatures must be considered an important factor. Furthermore, to evaluate the safety of structure, the recovery after cooling should be considered. Consequently, further researches on boundary temperatures and cooling effect for other properties of wood in elevated temperatures should be carried out in the future.

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