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Kim, Gwang-Chul
Department of Housing environmental design, College of Human Ecology, Chonbuk National University

Matsumura, Junji
Laboratory of Wood Science, Division of Sustainable Bioresources Sciences, Department of Agro-environmental Science, Faculty of Agriculture, Kyushu University

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Study on the Change of Bending Capacity of Wood Member by Accelerated Weathering Test

Gwang–Chul KIM[1] and Junji MATSUMURA[2]

Laboratory of Wood Science, Division of Sustainable Bioresource Science, Department of Agro–environmental Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan

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It is necessary to analyze the long–term stability of ancient wooden buildings. However, it is not practical to carry out real–time studies, so accelerated weathering tests have been devised to investigate the change of bending capacity of the wood. Each cycle consisted of seven steps, and it took one week to complete a cycle and the test was performed over nine weeks. There were decrease in the specific gravity and MC in the early parts of the test was due to reduction in the extracts. A great reduction in specific gravity of the specimens was observed after nine–weeks of accelerated weathering and the values of ultimate bending loads were consistent until the middle of the experiment. Finally, a sharp decrease in performance was seen among the test groups after nine weeks of accelerated weathering. Based on these facts, we have determined that the reduction in performance of wooden members is time dependent; therefore, it is necessary to establish a standard of performance assessment for existing buildings, through complementary testing of actual sites. In addition, further investigation using structural size member is required because only specific gravity greatly affects the strength in the case of small clear specimens.

Key words: accelerated weathering, ancient wooden building, specific gravity, ultimate bending load.

INTRODUCTION

Most historical artifacts of Korean cultural heritage which exist today are made of wood, except for a small number of stone towers and stone *Buddha*. It is quite interesting to note that these wooden artifacts and buildings have remained in–tact, in spite of natural weathering processes such as rain and wind, and as potential damage from other factors, such as humans. Beam & column construction accounts for the majority of traditional Korean timber structures. Various natural conditions, such as surrounding humidity and temperature, affect the longevity of these ancient buildings, but the most significant influencing factor is thought to be the strength of the timber structure itself, in terms of both the type of wood used, and the architecture and construction. (Kim *et al.*, 2010; Kim *et al.*, 2011; Kim, 2011)

Traditional Korean houses and temples are affected by dilapidation through natural factors, such as rain and sunlight, to a lesser extent than foreign wooden structures, by virtue of the special features of eaves and cornerstones. However, these ancient building have been deserted for long periods of time prior to any preservation efforts, and in most cases such buildings have been, or currently are, in poor states of repair.

Non–destructive testing (NDT) has revealed that a historical regional educational institutes (*Hyanggyo*) maintain their outer appearance, but in actual fact, only a small number of them had maintained their original function. (Kim *et al.*, 2013; Kim *et al.*, 2003; Kim *et al.*, 2001)

It is necessary to analyze the long–term stability of such structures, under conditions representing the surrounding environment, so as to better understand the structural integrity of such ancient wooden buildings. However, it is not practical to carry out real–time studies, given the age of the materials in question, and so, accelerated weathering tests have been devised to investigate the change of bending capacity of the wood.

MATERIALS AND METHODS

Accelerated weathering test

Figure 1 depicts the specimens, with dimensions of 30 mm×30 mm×500 mm, which were loaded into an accelerated weathering test apparatus. In this study we tested Korean red pine, which have been widely used in Korea as structural members.

It was ensured that a significant area of the specimen was exposed to the surrounding temperature, humidity and illumination, so as to maximize the effect of these variables, by placing the specimens with a gap at the top and bottom. The accelerated weathering apparatus used was a Model LCE–610 (Labtech).

The varying conditions of temperature, humidity and illumination used for this study are shown in Table 1. Each cycle consisted of seven steps, as shown in Table 1, and each step lasted for 24 h. Therefore, it took one week to complete a cycle and the test was performed over nine weeks (Kim, 2012)

50 specimens were extracted in serial order and were investigated for bending strength after stabilization using a thermo–hygrostat after each cycle of accelerated weath-

[1] Department of Housing environmental design, College of Human Ecology, Chonbuk National University, Jeonju 561–756, Korea

[2] Laboratory of Wood Science, Department of Agro–environmental Science, Division of Sustainable Bioresources Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan

* Corresponding author (E–mail: gckim@jbnu.ac.kr)

Table 1. The step composition of accelerated weathering test (Kim, 2012)

Step	Temperature (˚C)	Humidity (%)	Illumination (Lux)*	Time (hr)
1	10	30	1200×8+4000=13,600	24
2	20	40	1200×8+4000=13,600	24
3	30	50	1200×8+4000=13,600	24
4	40	60	1200×16+4000=23,200	24
5	50	70	1200×16+4000=23,200	24
6	60	80	1200×16+4000=23,200	24
7	70	90	1200×16+4000=23,200	24

*Illumination = fluorescent light (1200 lux/one) + metal halide (4000lux), wavelength=450 nm.

Fig. 1. Accelerated weathering test apparatus.

ering test total n=450 specimens. Two pieces were obtained from each specimen after they had been applied to a bending strength test, and determinations of MC and specific gravity were then carried out. The overall experiment was performed according to a prior paper (Kim, 2012).

Bending strength test

The test was performed using a central concentrated load experiment, according to the guideline of ASTM D143–94. The rate of loading was 5 mm/min, and the maximum span of 370 mm was used. The collected data of loading and deformation was saved using a PC, and was converted into excel file format as a load–deformation curve. A universal test machine with maximum capacity of 1 ton was employed for the bending strength test, as shown in Figure 2. Each group of 50 specimens was tested for bending strength.

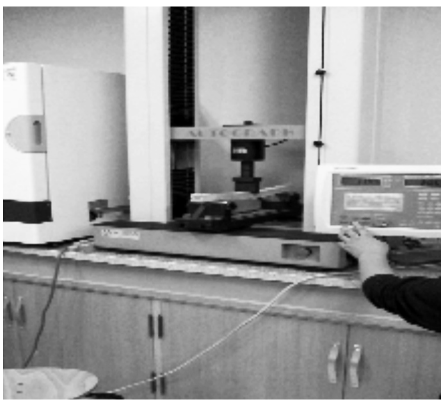

Fig. 2. Universal testing machine.

Measurement of the physical properties

Two subsamples, with dimension of 30 mm×30 mm ×30 mm, were collected from each specimen after determining the bending strength. Weights of the specimens were recorded every 6 h until the specimens were completely dried in the oven. MC and specific gravity were then determined.

Three parts for each specimen, the middle and each end, were measured for width, length and height of the block after the experiment using a digital vernier calipers, and the weight was recorded to two decimal places using an electronic scale by frequent zero adjustment for precise and accurate measurement.

RESULTS AND DISCUSSION

Basic physical properties

The moisture content and oven–dry specific gravity of the specimens of the nine test groups and control group (total n=500) are represented in Table 2 and Table 3.

The oven–dry specific gravity was measured, and even though slight decrease was observed in the early stages of the test, the values were similar between accelerated weathering groups and the control group. It is speculated that the decrease in the specific gravity observed in the early parts of the test was due to reduction in the extracts. It is thought, however, that changes in micro–structure or strength reduction from continuous exposure to high temperature, high humidity and illumination might have resulted in the dramatic reduction in oven–dry specific gravity of the group number 9. The further research will need from an anatomical standpoint. However, possibility that a rapid decrease in performance is predicted from the accelerated weathering test after nine weeks has been suggested.

The statistical significance of variance analysis was assessed to compare the difference between the control

Table 2. Oven–dry specific gravity of the specimens for control group and accelerated weathering groups

	Control	Cycle1	Cycle2	Cycle3	Cycle4	Cycle5	Cycle6	Cycle7	Cycle8	Cycle9
Avg.	0.46	0.45	0.43	0.43	0.44	0.41	0.42	0.47	0.45	0.38
St.dv.	0.10	0.07	0.08	0.10	0.05	0.05	0.04	0.07	0.09	0.04

Table 3. Moisture contents of the specimens for control group and accelerated weathering groups

	Control	Cycle1	Cycle2	Cycle3	Cycle4	Cycle5	Cycle6	Cycle7	Cycle8	Cycle9
Avg.	11.62	24.72	35.72	10.39	9.34	10.24	10.25	10.15	10.32	8.56
St.dv.	2.08	8.74	24.53	1.26	1.37	0.41	1.25	0.62	0.73	1.02

and the test groups.

Appendix 1

The F value of 13.2 was higher than the F–limit value of 1.89 and the significant probability was very low. This shows the significant differences among the groups, and confirms a significant difference of specific gravity within the groups.

Table 3 shows the increase of the MC in the first 2 weeks in the early parts of the test. This is thought to be due to the effect of humidity being larger than the effects of temperature and illumination in the early parts of the test. Like specific gravity, the statistical significance of the MC data was assessed by variance analysis so as to compare the control and the test groups.

Appendix 2

Similarly, the F value of 109.13, much higher than the F–limit value of 1.89 and the significant probability was very low. This reflects a significant difference in moisture content among the groups. Therefore, it is conjectured that there are significant difference in moisture content of the test and control groups statistically though the average values of the moisture content of the two groups were found to be similar.

Results of bending strength test (this should come first as it was performed first)

Failure types among groups

Fig. 3 shows the load–deformation curve of the control group and accelerated weathering test groups. Combinations of ductile and brittle strength were observed, as are commonly observed for wooden members. Because the specific fracture mode analysis of each specimen was determined according to ASTM is differ the object of this study, one–by–one analysis is not shown in this paper but simple tension and cross grain tension occupies the large portion.

Bending capacity comparison between accelerated weathering groups and control group

The ultimate bending loads and maximum deforma-

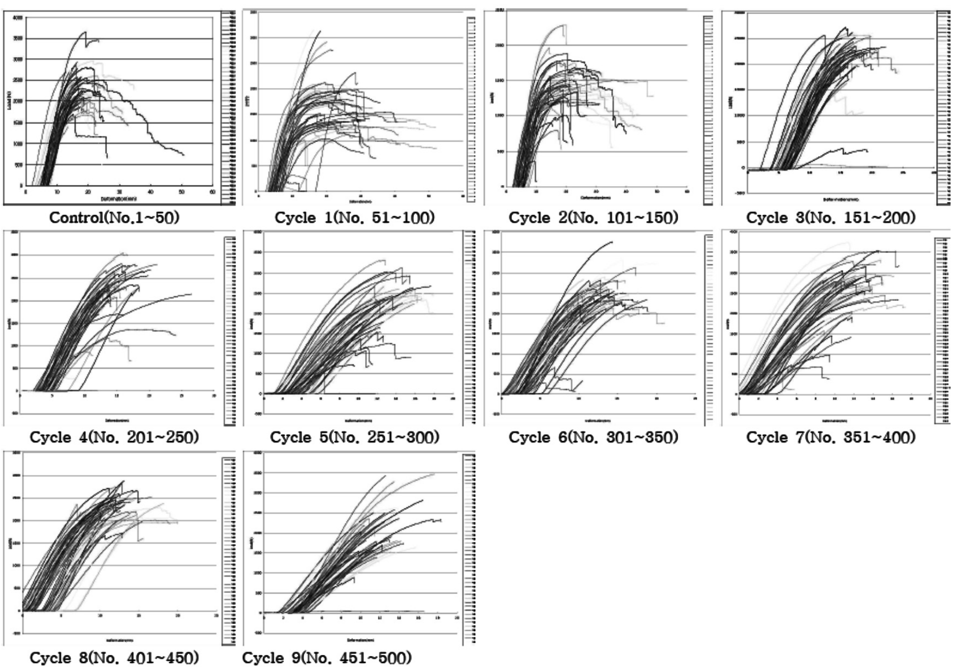

Fig. 3. Load–deformation curves for the accelerated weathering groups and control group.

Table 4. Ultimate load (N) of the specimens for control group and accelerated weathering groups

	Control	cycle1	cycle2	cycle3	cycle4	cycle5	cycle6	cycle7	cycle8	cycle9
Avg.	2280	1666	1426	2100	2128	2128	2382	2409	2279	1932
St.dv.	401	605	335	480	662	617	606	763	278	638

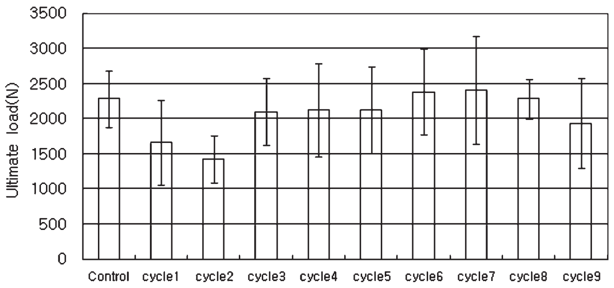

Fig. 4. Comparison of the ultimate loads among the accelerated weathering groups and control group.

tions of accelerated weathering groups and control group are shown in Table 4 and 5, respectively.

From Fig. 4, it is clear that the average value of ultimate loads of the control group was greater than the average values of the test groups in the early parts of test, which imply that the longer the exposure to the accelerated weathering condition, the lower the ultimate loading values. However, unlike specific gravity and MC, there were no noticeable differences in the middle parts of test. It is speculated that there are no distinct difference in ultimate load considering the fact the change in specific gravity is minimal.

There might exist drastic difference in the ultimate load bearing capacities due to localized fracture from natural strength defective factors in case of structural size member, however, we used small clear specimen in this study, and based on the test results, the specific gravity values exerts the greatest impact on the maximum capacity and consequently further investigation on the structural size specimen is required.

A great reduction in specific gravity of the specimen was observed after nine–weeks of accelerated weathering and the values of ultimate bending loads were consistent until the middle of the experiment. Finally, a sharp decrease in performance was seen among the test groups after nine weeks of accelerated weathering. Based on these facts, we have determined that the reduction in performance of wooden members is time dependent, and it is hence, necessary to establish a standard of performance assessment of the existing buildings through complemented experiment from actual sites.

Even though no difference was observed when the average values of ultimate bending capacity for accelerated weathering groups were compared, variance analysis was performed to investigate whether this difference is due to statistically significant disparity.

Appendix 3

The F value was quite higher than the F–limit values, with 16.06 and 1.89 respectively. The significant probability value of 3.78E–23 was found to be very low, and hence, a significant difference between the groups was determined. It also indicates the difference in ultimate bending values among the groups.

Comparison of deformation among groups

As represented in Table 4, the maximum deformation is high compared to the control group during the early parts of the test, during which the ultimate bending capacity was decreasing.

The early parts of the test showed high rates of deformation due to the influence from high humidity but the specimens started to stabilize and resulted in steady deformation from the middle parts of the test. It was also observed that the overall standard deviation of deformation was also small from the middle parts of the test and this reflects stabilization of the specimen after being affected equally by temperature, humidity and illumination.

Significance testing was performed to determine whether the difference in deformation between accelerated weathering groups was statistically significant.

Appendix 4

The F value determined was 44.49, which is higher than the F–limit value of 1.89 and the significant probability was found to be very small. Hence, this shows the statistical significance in maximum deformation among the groups. In other words, the accelerated weathering test was effective.

CONCLUSION

The change of bending capacity for wooden member by short–term accelerated weathering test studied for the purpose of understanding the structural safety of

Table 5. Deformation (mm) at the ultimate load of the specimens for control group and accelerated weathering groups

	Control	cycle1	cycle2	cycle3	cycle4	cycle5	cycle6	cycle7	cycle8	cycle9
Avg.	17.4	20.6	19.5	16.5	14.7	12.9	13.0	11.3	12.7	11.9
St.dv.	2.0	6.1	5.1	2.2	3.6	2.4	2.8	2.8	2.6	2.3

ancient wooden buildings.

The specific gravity and MC decreased in the early parts of the test due to extract losses. As the accelerated weathering test progressed, however, specimens started to stabilize. The bending capacity decreased at first, following the change of specific gravity, while the deformation increased during the early parts of the test but the values became similar from the middle parts of the test, as did the change of MC and specific gravity.

It is concluded that nine–weeks of accelerated weathering was responsible for a reduction in performance, considering the fact that rapid decrease in specific gravity and bending capacity were observed throughout the test. Therefore, it is necessary to establish a standard of performance assessment for existing buildings, through complementary testing of actual sites. In addition, further investigation using structural size member is required because only specific gravity greatly affects the strength in the case of small clear specimens.

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APPENDIX

Appendix 1
analysis of variance: one–way design of experiment

Groups	Count	Sum	Mean	Variance		
Column 1	95	43.28088	0.455588	0.009901		
Column 2	95	42.56664	0.44807	0.005087		
Column 3	95	40.49656	0.42628	0.006082		
Column 4	95	40.86747	0.430184	0.010896		
Column 5	95	41.8106	0.440112	0.002363		
Column 6	95	38.71603	0.407537	0.002072		
Column 7	95	39.77802	0.418716	0.001861		
Column 8	95	44.57706	0.469232	0.004794		
Column 9	95	43.1305	0.454005	0.008688		
Column 10	95	35.69443	0.375731	0.001942		
Anova						
Groups	Count	Sum	Mean	Variance	P–value	F–limit
Treatment	0.638882	9	0.070987	13.22265	4.63E–20	1.889824
Error	5.046466	940	0.005369			
Total	5.685348	949				

Appendix 2
analysis of variance: one-way design of experiment

Groups	Count	Sum	Mean	Variance		
Column 1	95	1103.578	11.61661	4.326342		
Column 2	95	2348.579	24.72188	76.39181		
Column 3	95	3392.935	35.71511	601.7036		
Column 4	95	986.806	10.38743	1.595277		
Column 5	95	887.0803	9.337688	1.883468		
Column 6	95	972.6758	10.23869	0.168697		
Column 7	95	974.1006	10.25369	1.568277		
Column 8	95	964.2882	10.1504	0.388245		
Column 9	95	980.8623	10.32487	0.534833		
Column 10	95	812.7485	8.555247	1.04445		
Anova						
Factor	SS	DF	MS	F	P-value	F-limit
Treatment	67730.93	9	7525.659	109.13	1.8E-139	1.889824
Error	64822.87	940	68.9605			
Total	132553.8	949				

Appendix 3
analysis of variance: one-way design of experiment

Groups	Count	Sum	Mean	Variance		
Column 1	50	113987.6	2279.752	160731.1		
Column 2	50	83282.97	1665.659	366241.8		
Column 3	50	71316.41	1426.328	112157.8		
Column 4	49	102879.1	2099.574	230512.6		
Column 5	50	106424.2	2128.484	437793.6		
Column 6	50	106392.3	2127.847	380934.4		
Column 7	50	119084.6	2381.692	367351.3		
Column 8	49	118035.3	2408.883	582399.1		
Column 9	50	113968	2279.36	77080.82		
Column 10	50	96602.86	1932.057	406882.5		
Anova						
Factor	SS	DF	MS	F	P-value	F-limit
Treatment	45096562	9	5010729	16.06918	3.78E-23	1.899062
Error	1.52E+08	488	311822.2			
Total	1.97E+08	497				

Appendix 4
analysis of variance: one-way design of experiment

Groups	Count	Sum	Mean	Variance		
Column 1	50	868.632	17.37264	3.997326		
Column 2	50	1027.689	20.55378	37.0337		
Column 3	50	976.796	19.53592	26.33084		
Column 4	49	807.42	16.47796	4.797594		
Column 5	50	736.406	14.72812	13.02181		
Column 6	50	646.686	12.93372	5.976874		
Column 7	50	650.215	13.0043	7.903451		
Column 8	49	554.885	11.32418	8.073233		
Column 9	50	633.344	12.66688	6.702955		
Column 10	50	595.763	11.91526	5.394926		
Anova						
Factor	SS	DF	MS	F	P-value	F-limit
Treatment	4784.237	9	531.5819	44.49962	4.01E-58	1.899062
Error	5829.532	488	11.94576			
Total	10613.77	497				