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Lin, Han Chien
Department of Forest Products Science, College of Agriculture, National Chiayi University

Ohuchi, Takeshi
Laboratory of Woodworking, Department of Technology, Fukuoka University of Education

Murase, Yasuhide
Laboratory of Wood Material Technology, Division of Biomaterial Science, Department of Forest and Forest Products Sciences, Faculty of Agriculture, Kyushu University

Tsai, Jung-Ting
Graduate Student, Department of Forest Products Science, College of Agriculture, National Chiayi University

他

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CEM Techniques and X–ray Analytical Microscope Analysis for Evaluating the Combustion Emissions and Char of CCA– and ACQ–Treated Woods after QUV Degradation

Han Chien LIN[1,*], Takeshi OHUCHI[2], Yasuhide MURASE[3], Jung–Ting TSAI[4] and Chi–Chun KAO[5]

Laboratory of Wood Material Technology, Division of Biomaterial Science, Department of Forest and Forest Products Sciences, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan

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Two types of preservative–treated woods, CCA– (chromated copper arsenate) and ACQ– (ammoniacal copper quats) treated specimens, and *Taiwania cryptomerioides* Hay (Taiwania), as a control specimen, were used in this study. They underwent an accelerated weathering test that consisted of QUV degradation for 0, 104, 200, 400, and 800 h. The emission gas concentrations of O_2 and CO_2, the emission contents (CO, SO_2 and NO_X) and the temperature of the emission gases during the combustion of the specimen were measured using Continuous Emission Monitoring (CEM) techniques. X–ray Analytical Microscope (X–ray) Analysis and Elemental Analysis (EA) were used to examine certain residual elements of the char as well as particles from each specimen before combustion. The objectives of this study were to investigate the pollutants from both preservative–treated woods, compare them with those of Taiwania, and assess them as a reference of emission quantity for air pollution. When the specimens that had been subjected to QUV degradation were combusted, the emission gas temperatures of all specimens rose rapidly to about 210–235 °C, then increased slowly up to 260–270 °C and then lowered back down to a steady temperature in the 210–220 °C, shown as a plateau curve. The concentration of O_2 decreased linearly from 20.7% to about 16.4–17.5%, and the concentration of CO_2 increased from 0.2% to about 2.3–3.4%. Both O_2 and CO_2 had a close relationship during the combustion. The highest emission quantities of CO and NO_X for the CCA–treated specimens were about 264.5–354.0 and 7.7–13.0 ppm, and for the ACQ–treated specimens the ranges were 131.5–281.5 and 23.5–29.5 ppm, respectively. SO_2 was not found in the emission gases during combustion of either of the preserved specimens. The result of the X–rays indicated that for the CCA–treated specimens, the main metal elements Cr, As, and Cu decreased from 0.0676 to 0.0320%, 0.0090 to 0.0079% and 0.0187 to 0.0089% respectively, but Cu for the ACQ–treated specimen decreased from 0.1198 to 0.0010%. The result of the EA indicated that prior to combustion, the amount of N (0.30%) is higher for the ACQ–treated woods than that for the CCA ones; therefore, the NO_X gases during combustion were higher for the ACQ–treated woods.

Keywords: Preservative–treated woods, Combustion Emissions, Char, QUV degradation

INTRODUCTION

The increased outdoor use of wood products is due to their protection with various preservatives, e. g. chromated copper arsenate (CCA) and ammoniacal copper quats (ACQ). In preservative treated–woods research a great deal of attention is always paid to the influence of amount of leaching that takes place after having been used in various outdoor applications for a longer period of time. This is because the larger the amount of leaching, the higher the level of deterioration of wood products when used in the outdoors continuously. The preservatives used to treat wood products have generally speaking disappeared after having been used for a long time, and any remnants are generally removed by combustion (Kuwahara, 1996; Jang, 1997; Kobayashi *et al*., 2000). Therefore, it seems necessary to determine the gaseous emissions such as carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrous oxides (NO_X) etc, during combustion (Kercher *et al*., 2001; Humphrey, 2002), of these discarded preservative–treated woods, regardless if they were treated with CCA or ACQ. In addition we should investigate the amount of char formed (residual metal) after combustion (Lin *et al*., 2006; Lin *et al*., 2007).

In a previous work (Lin *et al*., 2007) we established some referable results for both preservative–treated woods, involving CCA and ACQ water–based preservatives, and the combustion emissions during combustion and the char after combustion. The emission gas temperatures of all samples rose rapidly and then remained relatively steady at a temperature range shown as a plateau curve. Both the concentration of O_2 and CO_2 were closely related during the combustion. The highest

[1] Department of Forest Products Science, College of Agriculture, National Chiayi University, Chiayi, Taiwan, ROC
[2] Laboratory of Wood Working, Department of Technology, Fukuoka University of Education, Japan
[3] Laboratory of Wood Material Technology, Division of Biomaterial Science, Department of Forest and Forest Products Sciences, Faculty of Agriculture, Kyushu University, Japan
[4] Graduate Student, Department of Forest Products Science, College of Agriculture, National Chiayi University, Chiayi, Taiwan, ROC
[5] Undergraduate Student, Department of Forest Products Science, College of Agriculture, National Chiayi University, Chiayi, Taiwan, ROC
* Corresponding author (E–mail: alexhlin@mail.ncyu.edu.tw)

quantity of CO emission was about 159.3 ppm for the ACQ specimen and 108.0 ppm for the CCA specimen. The quantity of SO_2 emission for both types of samples was zero. The maximum NO_X for the ACQ specimens was about 23.5 ppm and the basic pollutant was from BKC (N–alkyl benzyl dimethyl ammonium chloride) during the combustion. The result of the EDX (Energy Dispersive X–ray Spectrometer) analysis showed that the relative proportion of Cu was 2.67% for the ACQ specimen, and that ACQ–1 (the type 1 of ACQ) was left with a high amount of Cu, 50.14%, but that the char of the CCA specimen had an amount of Cr (7.38%) that was obviously higher than that of As (4.08%) and Cu (5.18%).

The objectives of this research were to investigate the combustion emissions and char of CCA– and ACQ–treated woods after QUV degradation, an accelerated weathering test. Our goals were to obtain a reference for the gas emitted creating air pollution and hopefully to acquire a fundamental knowledge of the residual elements of the char. The examination in this study has been divided into two categories. The first is related to the research in combustion emissions from preservative–treated woods before/after QUV degradation, using a continuous emission monitoring (CEM) technique. The second category of examination applies the X–ray analytical Microscope analysis (X–ray) and Elemental Analysis (EA) to examine certain residual elements of the char before/after QUV degradation, and also to compare it with both preservative–treated woods before combustion. The emissions from the discharge gases during the preservative–treated specimen combustion before/after QUV degradation and the residual elements of the char before/after combustion were investigated, respectively.

MATERIALS AND METHODS

Preparations of the control specimen and the preservative–treated woods

Taiwania cryptomerioides Hay (Taiwania), was used as the control specimen (untreated wood), and two types of commercial Chromated Copper Arsenate (CCA)– and Ammoniacal Copper Quats (ACQ)–treated woods (Taiwania), were provided by Kunnyih Co. Ltd., Taiwan.

All specimens were clear wood, measuring 110 mm long × 75 mm wide × 6 mm thick. They were prepared and air–dried at ambient temperatures until they had a moisture content of less than 15.0%. The manufacturing standard of the preservative–treated woods was in accordance with CNS 3000 O1018 (2001). Two types of wood preservatives were used: type 3 of CCA (CCA–3) and type 1 of ACQ (ACQ–1). The basic contents and the basic properties of both wood preservatives were the same as in previous reports (Lin *et al*., 2006; Lin *et al*., 2007; Lin and Murase, 2007). The "Breant–Bethell" procedure, a full–cell treatment was applied using a laboratory type of pressure impregnation facility. The condition of the full–cell treatment and the average amount of impregnation of both wood preservatives were the same as in previous reports (Lin *et al*., 2006; Lin *et al*., 2007). Both treated woods are considered grade k 3 in the CNS 3000 (2001) in Taiwan. All specimens underwent the accelerated weathering test prior to the emissions test of the discharge gases during combustion.

Basic properties of the preservative–treated specimens

Density and moisture content

All specimens were conditioned to equilibrium at 20 °C with 65% relative humidity (RH) for about four weeks. The average density and moisture content of Taiwania and either the CCA– or the ACQ–treated specimen before QUV degradation were measured in accordance with CNS 451 O2002 (1996) and CNS 452 O2003 (1996), respectively.

Surface texture

The surface texture of each specimen was measured using a surface texture–measuring instrument (Semitsu, Tokyo). The average degree of surface texture on the centerline of the specimen (Ra), the degree of texture at the highest point on the surface of the specimen (Rmax), and the average degree of texture for ten points on the surface of the specimen (Rz) were measured.

Color value

The specimens for Taiwania and both CCA– and ACQ–treated specimens were measured using a colorimeter (Nippon Denshoku NR–3000) at 3 randomly selected spots. In the CIE 1976 L* a* b* color system employed in this study, color is considered to consist of three major dimensions: hue, chroma, and lightness. L* is the lightness or brightness variable and is generally the most important aspect of wood color changes to a viewer's eye, while a* and b* represent the chromaticity (hue and chroma) coordinates.

Accelerated weathering tests

The accelerated weathering tests (QUV degradation) were carried out by a Q–U–V accelerated weathermeter (Q–Panel Co.). The conditions for an experimental cycle were temperature 60 °C with 4 h UV (ultraviolet) irradiations and temperature 40 °C with condensation of mist exposure for 4 h according to ASTM G53–83. Seventy–two specimens impregnated with CCA–3 or ACQ–1 and 18 control specimens were processed, that is, six replicates of each sample were prepared and treated with 0, 13, 25, 50, and 100 cycles. In other words, the course of QUV degradation was 0, 104, 200, 400, and 800 h. Afterwards, all specimens were investigated for emission from the discharge gases during combustion, and the chars were analyzed using an Elemental Analyzer and the X–ray analytical Microscope.

Experimental combustion methods

Continuous Emission Monitoring (CEM) techniques are widely utilized for detecting gaseous emissions such as CO, SO_2, NO_X, and O_2 and CO_2 concentrations at the chimney exit of furnaces to determine the concentrations of various pollutants (Jang, 2000; Ladomersky,

2000). A Flue–gas Analyzer (MSI 2000, W. Germany) was used to examine the gas emitted from a flammability test cabinet (with reference to CNS 7614 A3125, NCYU handmade). The experimental design and tested methods for the CEM techniques were the same as for the previous report (Lin *et al*., 2001; Lin and Huang, 2004; Lin, 2005; Lin *et al*., 2007). The first cycle run in the flue–gas analyzer did not include combustion with a specimen in the test cabinet to be certain that the measured value of various emission gases was zero and that the gas temperature was at room temperature. The specimen was ignited and then examined for 9 cycles continuously. The CO, SO_2 and NO_X gases were determined according to parts per million (ppm). The O_2 and CO_2 concentrations were defined as the volume percent (VOL %) of the air in the emission exit. The gas temperature was measured at the same time.

X–ray analytical Microscope analysis (X–ray)

In the experiments in this study, samples of about 10 g each were prepared individually. The trace heavy metals, Cr (chromium), As (arsenic), Cu (copper) etc, of the residual char of the CCA– or ACQ–treated woods after combustion and the specimens before combustion were analyzed using a Fluorescence X–ray analyzer for harmful element Inspection (HORIBA XGT–1000WR TYPE1, Japan). For all investigations the X–ray tube of the X–ray analytical Microscope was set at 50.0 kV with a minimum beam of X–ray 1.2 mm, in order to obtain the trace heavy metals from all specimens. To determine the peak of each element (%), the measured duration of the X–ray count (count per second, cps) was set at 200 sec with over 10 points observation. The results of the residual elements in the char for the specimens after the combustion and the specimens before combustion were then analyzed.

Elemental Analysis (EA)

The samples, about 2–4 mg each, before and after combustion were individually analyzed using an Elemental Vario CHNS/O analyzer (EA, Germany). The results for the carbon (C), nitrogen (N), sulfur (S), and hydrogen (H) elements were then determined.

Statistical analysis

The results of the EA and X–ray analytical Microscope of various specimens were statistically analyzed based on Duncan's multiple range tests at 5% significant level analysis, using the Statistical Package for Social Science (SPSS) software.

RESULTS AND DISCUSSION

Basic properties

The basic properties, including density, moisture content, surface texture and color value, of Taiwania and both preservatives–treated specimens are shown in Table 1. Based on the type of specimen, the density and moisture content varied insignificantly (5%) by Duncan's multiple range tests, expressed by the same letters, even for different types of specimens. The average moisture content of all specimens was about 12%, and the density at this moisture content was about 0.39 g/cm^3. When comparing the surface texture between the control specimens and both preservative–treated woods, Duncan's multiple range tests varied significantly. In general, a porous material can contribute to swelling/absorption of the constituents and change the direction of the micro–fibers after soaking with a water type of solution (Takeuchi, 2000). For the color value, the results showed that the changes for L* a* b* in both CCA– and ACQ–treated specimens were significant compared with the control. This is due to the types of experimental preservatives used: CCA–3 and ACQ–1 were deeply colored solutions; the color of CCA–3 is a yellow–green and ACQ–1 is a deep blue.

Emission gases from the control wood and the preservative–treated woods before/after QUV degradation

Figure 1 shows the relationships between emission gas temperatures, the concentration of O_2 and CO_2 and the combustion time for these specimens before/after QUV degradation. The gases emitted by 90 specimens during combustion were examined. The specimens were divided into 3 groups, including the control, CCA– and ACQ–treated woods, with 30 specimens in each group. In other words, the specimens were processed under accelerated weathering conditions for 104, 200, 400 and 800 h. The results were then compared with the control specimens of 0 h (unprocessed with QUV degradation).

The increase in emission gas temperature corre-

Table 1. Basic properties of the control and preservatives–treated specimens

Specimen[1)]	Density (g/cm^3)	Moisture content (%)	Surface texture (μm)[2)]			Color values[3)]		
			Ra	Rz	Rmax	L*	a*	b*
Taiwania	0.38 (0.02)[a 4)]	12.97 (0.05) [a]	2.23 (0.60)[a]	12.40 (2.37)[a]	18.77 (4.58)[a]	56.62 (2.05)[a]	15.46 (5.75)[a]	29.23 (3.66)[a]
CCA–treated specimens	0.39 (0.03)[a]	12.18 (0.53)[a]	3.31 (1.11)[b]	15.03 (5.19)[b]	23.49 (6.65)[b]	63.19 (1.84)[b]	8.47 (5.32)[b]	24.52 (5.09)[b]
ACQ–treated specimens	0.39 (0.01)[a]	12.78 (1.46)[a]	2.35 (0.70)[ab]	13.75 (4.17)[ab]	21.61 (5.13)[b]	52.55 (5.30)[a]	10.46 (6.53)[b]	22.93 (6.18)[b]

1) Taiwania: *Taiwania cryptomerioides* Hay; CCA: chromed copper arsenate; ACQ: ammoniacal copper quate.
2) Surface texture – Ra: Average surface texture degree on centerline of specimen; Rmax: Texture degree of maximum high point on surface specimen; Rz: Texture degree for average ten points on surface specimen.
3) Color values – L*: 0 to 50 dark direction, 51 to 100 light direction; a*: 0 to +60 red direction, 0 to –60 green direction; b*: 0 to +60 yellow direction, 0 to–60 blue direction.
4) Mean (standard deviation) separation within columns by Duncan's multiple range tests at 5% significant level.

sponded to the increase in combustion time for each type of specimen, increasing linearly to about 210–235 °C from the start of the combustion treatment. Subsequently, this increasing tendency resulted in a continuous but slow increase of the emission gas temperature to about 260 to 270 °C , and then lowered back down to a steady temperature in the 210–220 °C , shown as a plateau curve. The results of the change in O_2 and CO_2 concentrations showed that an increase of CO_2 and a decrease of O_2 corresponded to the increase in combustion time for the specimens shown in the middle and bottom of Fig. 1. The increase in CO_2 and the decrease in O_2 had a linear tendency from the start of combustion. The control and two types of preservative–treated specimens showed a range of O_2 concentration linearly decreasing from 20.7% to about 16.4–17.5%. On the contrary, the concentration of CO_2 increased from 0.2% to about 2.3–3.4%. The results also showed that the increase

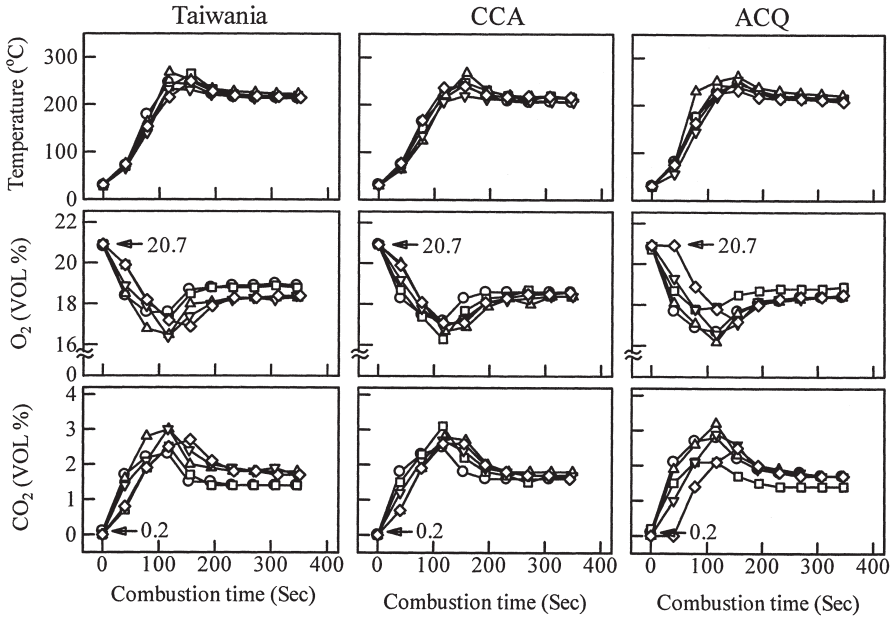

Fig. 1. Relationships between combustion time and emission gas temperature, O_2, CO_2 concentration for various experimental specimens.
Symbols: Various specimens were processed with the time of QUV degradation. –○–: 0 h; –□– : 104 h; –△– : 200 h; –▽–: 400 h; –◇–: 800 h.
Notes: Abbreviations of Taiwania, CCA and ACQ are the same as Table 1.

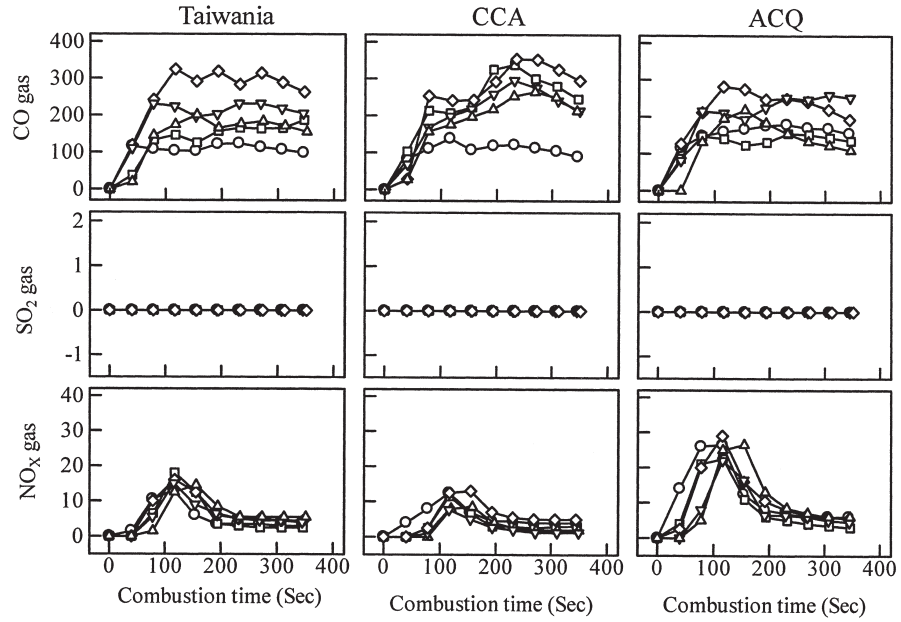

Fig. 2. Relationships between combustion time and emission contents (ppm), CO, SO_2 and NOx gases for various experimental specimens.
Notes: Abbreviations and symbols of Taiwania, CCA and ACQ are the same as Table 1 and Figure 1.

in CO_2 and the decrease in O_2 before QUV degradation were lower at either maximum or minimum point (about 115 to 117 sec) than after QUV degradation. This seems to indicate that the ignition point and/or the heat decomposition of the different preservatives may influence the combustion time and change the concentration of O_2 and CO_2 during gaseous emissions. After the peak point of CO_2 and the lowest point of O_2 were reached, the concentration of O_2 and CO_2 slowed down until complete combustion was reached at about 18.2–18.9% and 1.4–1.8% respectively. The concentration of O_2 showed to be negatively related and CO_2 showed to be positively related to the emission gas temperature. The concentration of O_2 and CO_2 are closely related to each other. This result agrees with those of previous works (Lin *et al*., 2001; Lin and Huang, 2004; Lin, 2005; Lin *et al*., 2007).

To show that the preservative–treated specimens produced serious pollution gases, CO. SO_2 and NO_x, before/after QUV degradation, the combined results of the emission contents are shown in Fig. 2. The results showed that the peak for the CO gas of Taiwania were at 40 sec with 116.0 ppm; for the CCA specimens a maximum value of CO was obtained at about 115 sec with 108.0 ppm, and for the ACQ specimens the peak of the CO gas increased linearly to about 80 sec with 159.3 ppm. After that, all specimens before QUV degradation became a plateau curve and remained so until the end of the combustion time. However, the amount of CO gas for the specimens after processing with the accelerated weathering tests increased even though the emitted CO gas was the same as that of the specimens before QUV degradation. This indicates that the emission of CO gas is not only related to the ignition time (Ladomersky, 2000; Lin *et al*., 2001) of the specimens with different types of preservatives (Lin *et al*., 2007), but also to either CCA– or ACQ–treated wood resulting in incomplete combustion due to the influence of time degradation, inferring that the preservatives were leached from the surface of the specimens. The highest point of CO gas for Taiwania after QUV degradation was about 146.0–324.0 ppm, 264.5–354.0 ppm for CCA–treated wood, and 131.5–281.5 ppm for ACQ–treated wood. When comparing the CO emitted quantity to that emitted by Taiwania and both preservative–treated specimens after QUV degradation, it shows that the specimens treated with CCA–3 produced the highest quantity and were also higher than the specimens before QUV degradation by about 250 ppm.

As expected, in this experiment there was no emission of SO_2 in the emission gases during the combustion of Taiwania and both preservative–treated specimens before/after QUV degradation because the sulphur content was not included in 2 types of preserved woods from their typical chemical compounds (Nicholas and Schultz, 1994). It is suggested that the specimens treated with either CCA–3 or ACQ–1 before/after time degradation in this study are not the origin of the SO_2 in environment when it comes to final disposal (combustion).

The results in Fig. 2 also show that the Taiwania and both preservative–treated specimens before/after QUV degradation all produced the emission gas, NO_x. However, during the combustion of Taiwania and the specimen treated with CCA–3 they produced less NO_x than the specimens treated with ACQ–1, even though all specimens were processed with different time degradation. Lin *et al*. (2007) reported that ACQ–1 and BKC were more significant for the emission of NO_x during combustion. This is because the main combinations of ACQ–1 are BKC, and in addition nitrogen (N) is also included in the BKC (Nicholas and Schultz, 1994). This indicates that NO_x is a main source of pollution in wood with ACQ–1, even if the specimens treated with ACQ–1 were processed by different time degradation. The maximum NO_x for the specimens treated with ACQ–1 before/after time degradation was about 23.5–29.5 ppm. The NO_x gas was higher than that of the Taiwania (12.5–18.0 ppm) and the specimens treated with CCA–3 (7.7–13.0 ppm).

Char from preservative–treated woods before/after QUV degradation

An X–ray analytical microscope analyzer including a fluorescence X–ray can be applied directly to the material to check for harmful elements. It is a powerful tool for studying the minerals, expressing by relative percentage (%), in a material, especially for heavy metal trace elements, such as Cr, As, Cu etc. In this portion of the experiment, all specimens before/after being burned in a 45° flammability test cabinet were analyzed with a fluorescence X–ray analyzer (X–ray). The results are shown in Table 2.

The main elements of Taiwania and both preservative–treated woods before QUV degradation were CH_2, 99.9999% for the Taiwania, 99.9047% for the specimens treated with CCA–3, and 99.8802% for the specimens treated with ACQ–1. After combustion, the relative percentage of CH_2 was the same as the control specimen before the combustion, 99.9999%, but CH_2 gradually increased through the time degradation for both preservative–treated specimens. The results for the CCA–treated specimens showed that CH_2 decreased to 99.9300% for 200 h of QUV degradation, 99.9376% for 400 h and 99.9512 for 800 h. For the ACQ–treated specimens, CH_2 decreased to 99.9072% for 200 h, 99.9989% for 400 h and 99.9990 for 800 h. It is suggested that wood treated with either CCA–3 or ACQ–1 is basically considered to be a type of cellulose material (Humphrey, 2002), even if it has been through time degradation and combustion.

The results also showed that for CCA–treated specimens, the main metal elements (Cr, As, Cu) decreased through the time degradation; Cr went from 0.0676 to 0.0320% during 0 to 800 h, As went from 0.0090 to 0.0079% and Cu from 0.0187 to 0.0089%. As to the results of the ACQ–treated specimens, Cu decreased from 0.1198 to 0.0010% during 0 to 800 h of QUV degradation. These findings indicate that three types of compounds, CrO_3, AS_2O_5 and CuO, of CCA–treated woods and the main inorganic compound, CuO, of ACQ–treated wood had been leached out in the course of the time

Table 2. X–ray analytical Microscope analysis of various experimental specimens before the combustion Unit: %

Specimen[1)]	Element	Time of QUV degradation for the specimens after combustion			
		0 h	200 h	400 h	800 h
Taiwania	CH_2	99.9999 (0.0000)[a2)]	99.9999 (0.0000)[a]	99.9999 (0.0000)[a]	99.9999 (0.0000)[a]
	Cr	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]
	As	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]
	Cu	0.0001 (0.0000)[a]	0.0001 (0.0000)[a]	0.0001 (0.0000)[a]	0.0001 (0.0000)[a]
CCA–treated specimens	CH_2	99.9047 (0.0267)[a]	99.9300 (0.0000)[b]	99.9376 (0.0000)[c]	99.9512 (0.0000)[d]
	Cr	0.0676 (0.0000)[a]	0.0460 (0.0000)[b]	0.0420 (0.0000)[b]	0.0320 (0.0000)[c]
	As	0.0090 (0.0000)[a]	0.0088 (0.0000)[a]	0.0080 (0.0000)[a]	0.0079 (0.0000)[a]
	Cu	0.0187 (0.0000)[a]	0.0152 (0.0000)[b]	0.0124 (0.0000)[c]	0.0089 (0.0000)[d]
ACQ–treated specimens	CH_2	99.8802 (0.0158)[a]	99.9072 (0.0158)[b]	99.9989 (0.0006)[c]	99.9990 (0.0003)[d]
	Cr	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]
	As	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]	0.0000 (0.0000)[a]
	Cu	0.1198 (0.0036)[a]	0.0928 (0.0000)[b]	0.0011 (0.0002)[c]	0.0010 (0.0003)[c]

1) Abbreviations of Taiwania, CCA and ACQ are the same as Table 1.
2) Mean (standard deviation) separation within lines by Duncan's multiple range tests at 5% significant level.

Table 3. EA analysis of various experimental specimens before and after the combustion Unit: %

Specimen[1)]	Element	Before Combustion	Time of QUV degradation for the specimens after combustion			
			0 h	200 h	400 h	800 h
Taiwania	C	49.24 (0.02)[a2)]	79.58 (0.03)[b]	79.92 (2.67)[b]	79.50 (0.05)[b]	79.40 (0.35)[b]
	N	0.05 (0.02)[a]	0.28 (0.04)[b]	0.14 (0.00)[c]	0.16 (0.01)[c]	0.14 (0.02)[c]
	S	0.55 (0.02)[a]	1.17 (0.62)[a]	0.71 (0.19)[a]	0.57 (0.11)[a]	0.55 (0.12)[a]
	H	6.40 (0.15)[a]	3.27 (0.03)[b]	2.80 (0.04)[c]	3.06 (0.00)[d]	3.00 (0.01)[d]
CCA–treated specimens	C	49.05 (0.27)[a]	75.38 (0.54)[b]	76.26 (0.76)[b]	79.40 (0.35)[b]	81.20 (0.15)[b]
	N	0.06 (0.01)[a]	0.15 (0.01)[b]	0.13 (0.01)[b]	0.14 (0.02)[c]	0.13 (0.04)[c]
	S	0.44 (0.08)[a]	0.60 (0.04)[b]	0.62 (0.02)[c]	0.55 (0.12)[a]	0.50 (0.16)[a]
	H	6.66 (0.02)[a]	2.90 (0.04)[b]	2.82 (0.04)[bc]	3.00 (0.01)[d]	3.02 (0.02)[d]
ACQ–treated specimens	C	49.49 (0.16)[a]	80.93 (0.20)[b]	76.20 (0.11)[c]	75.41 (2.65)[c]	75.20 (0.95)[c]
	N	0.30 (0.02)[ab]	0.33 (0.01)[a]	0.26 (0.01)[b]	0.26 (0.00)[bc]	0.23 (0.01)[bc]
	S	0.54 (0.18)[a]	0.54 (0.08)[a]	1.47 (0.96)[a]	0.84 (0.14)[a]	0.80 (0.11)[a]
	H	6.76 (0.08)[a]	3.13 (0.03)[b]	2.81 (0.09)[c]	2.71 (0.08)[c]	2.81 (0.02)[c]

1) Abbreviations of Taiwania, CCA and ACQ are the same as Table 1.
2) Mean (standard deviation) separation within lines by Duncan's multiple range tests at 5% significant level.

degradation. From the above results, it is evident that the amount of leaching of the main element from the CCA–treated wood was less than that of the ACQ ones. This is because the fixation of CCA preservatives in the wood is better that that of ACQ one (Lebow, 1996; Temiz *et al.*, 2006). Moreover, based on time degradation, the variation in Cr content was insignificant (5%) by Duncan's multiple range tests, expressed by the same letters, indicating that Cr from the char of the CCA preservatives is a stable element. This result agrees with those of previous works (Hirata *et al.*, 1993; Kercher and Nagle, 2001; Cooper, 2003; Helsen and Bulck, 2005; Lee *et al.*, 2005; Lin *et al.*, 2007).

Furthermore, the specimens before/after having been examined in a 45 ° flammability test cabinet were analyzed with the Elemental Analyzer (EA). The results are shown in Table 3. The high level of carbon (C) for all specimens was about 75–80% after combustion was obtained, compared with the specimens (about 49.24–49.49%) before combustion. The results also show that before combustion, the amount of N (0.30%) was higher for ACQ–treated specimens than that for the Taiwania and the CCA samples, and that after combustion the N element decreased significantly (5%) by Duncan's multiple range tests, expressed by different letters. This infers that the ACQ–treated specimen can produce substantial amounts of NO_X gases (Fig. 2) during combustion, even if the specimen has been time degraded. The above results suggest that by using X–ray and EA to analyze the residual elements in char, the results can provide experimental data for referencing the char of preservative–treated woods.

CONCLUSIONS

This paper examined the emission gas concentration of the preservative–treated specimens before/after QUV degradation under combustion. The concentration of O_2 was negatively and that of CO_2 was positively related to the emission gas temperature. The main pollutants dur-

ing combustion were from the incomplete combustion and the chemical compounds of the preservatives. They are the main variables relating to the majority of emission contents (CO, NO_x), and the change of O_2 and CO_2 concentration in the air, even if the specimens were processed by QUV degradation. SO_2 was not produced during combustion because the two types of water–based preservatives used did not have a sulfur–base. The emission contents of preservative–treated woods after QUV degradation were higher than before QUV degradation, especially for CO gas. This is because the incomplete combustion occurring due to the influence of time degradation. The NO_x content in the emission from the combustion of ACQ–treated woods were found to produce more pollution gas than the others, even if the specimen was processed by time degradation. The result of the X–ray analysis indicated that the main element of this pollution gas was more than 95–99% CH_2 for the char after combustion. The results of the Cr, As and Cu analysis showed that the char of both preservative–treated specimens indicated the amount of leaching (%) that had taken place. The results of the EA analysis inferred that the ACQ–treated specimen produced NO_x gases during combustion, because prior to combustion, the amount of N (0.30%) was higher for ACQ–treated woods than for the other specimens.

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