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Effects of posttreatment with alkaline copper quat and copper azole on the mechanical properties of wood-based composites

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Abstract: The static bending strengths, modulus of rupture, and modulus of elasticity of 5 commercial wood-based composites [softwood plywood (SWP), hardwood plywood (HWP), medium density fiber-board (MDF), oriented strand board (OSB), and particleboard (PB)] were measured after a postmanufacture treatment of vacuum-impregnation with alkaline copper quat (ACQ) and copper azole (CA) (target retentions: 0.65, 1.30, and 2.60 kg m^{-3} for ACQ; 0.25, 0.50, and 1.0 kg m^{-3} for CA). Of the composites tested, SWP exceptionally sustained no damage to its bending strengths, regardless of preservative types and retentions. Others (HWP, MDF, OSB, and PB) were necessarily affected to some degree by posttreatments. In accordance with the dimensional stability and resistance to biological attacks, of the posttreated composites, SWP seems most suitable and implemental for posttreatment when the appropriate selection of treatment concentrations and schedules is made.

Key words: Alkaline copper quat, copper azole, mechanical properties, posttreatment, wood-based composites

1. Introduction

Wood-based composites have recently become widely utilized in the construction industry, mostly replacing solid lumber in nonstructural and structural applications (Laks 2002; Kirkpatrick and Barnes 2005). Since these composites are usually prone to biodegradation and biodeterioration when utilized in outdoor and ground contact conditions, proper protection is important to ensure their longer service life (Gardner et al. 2003). Wood-based composites can be protected by various methods during and after manufacturing. However, each method presents its own challenges in terms of effects on the mechanical properties of final products, preservative distribution, and difficulties in the manufacturing process. The most practical method could be postmanufacturing treatments by dipping, spraying, brushing, or vacuum-pressure. The major drawbacks of the postmanufacturing methods are related to unfavorable dimensional instability caused by wetting and drying, and a reduction in mechanical strength (Goroyias and Hale 2004).

Mitchoff and Morrell (1991), who studied the effects of a plywood source and the preservative chemicals chromated copper arsenate (CCA) and ammoniacal copper zinc arsenate (ACZA) on treatability, reported that ACZA posttreatment was better than CCA in penetration and retention values, without any change of mechanical properties. Posttreatment of yellow poplar laminated veneer lumber with creosote did not produce any unacceptable effect on preservative distribution, bending modulus of elasticity (MOE), or shear strength in adhesive line (Gardner et al. 2003). Similarly, glulam beams made from hardwoods and bonded with resorcinol-formaldehyde resin showed no negative effect on bond quality and the resulting mechanical properties after posttreatment with creosote (Gardner et al. 2003).

The objective of this study was to determine the effects of alkaline copper quat (ACQ) and copper azole (CA) posttreatment on bending properties [MOE and modulus of rupture (MOR)] of the 5 different composites tested. These preservative chemicals were chosen since they are widely accepted as alternatives to CCA and considered more environmentally friendly due to their arsenic- and chromium-free formulations. The retention levels were also evaluated against property reductions.

2. Materials and methods

2.1. Wood-based composites

Specimens (210 mm × 30 mm × thickness) included commercially available structural-use softwood plywood (SWP) [*Larix* spp.; 5-ply 0° / 90° construction; oven-dried density (o.d.d.) 0.59 g cm^{-3}; thickness 12.1 mm; bonded with boiled-water resistant exterior-type phenol-formaldehyde

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adhesive], hardwood plywood (HWP) (Dipterocarpaceae species; 5-ply 0° / 90° construction; o.d.d. 0.50 g cm^{-3}; thickness 11.7 mm; bonded with boiled-water resistant exterior-type phenol-formaldehyde adhesive), medium density fiber-board (MDF) (hardwood fibers; 3 layers of random fiber orientation; o.d.d. 0.71 g cm^{-3}; thickness 12.0 mm; bonded with melamine-urea-formaldehyde adhesive), oriented strand board (OSB) (aspen strands; 3 layers of random strand orientation; o.d.d. 0.63 g cm^{-3}; thickness 12.7 mm; bonded with phenol-formaldehyde adhesive), and particleboard (PB) (hard-/softwood mixed fibers; 3 layers of random fiber orientation; o.d.d. 0.71 g cm^{-3}; thickness 11.9 mm; bonded with melamine-urea-formaldehyde adhesive). The specimens were double-coated with a 2-component epoxy resin on each cut end, in order to simulate penetration characteristics of a full-size composite product, and conditioned at 60 ± 2 °C for 72 h before preservative treatments. The equilibrium moisture content of the composites was between 6% and 9% before the subsequent treatments. The minimum standards of 12-mm wood-based composites for bending strength are around 60, 45, 20, 22, and 13 MPa for SWP, HWP, MDF, OSB, and PB, respectively (Japanese Standards Association 2008).

2.2. Preservatives and target retentions

ACQ and CA, supplied respectively by Koshii Preserving Co. Ltd. (Osaka, Japan) and Xyence (Isezaki, Gunma, Japan), were used in this experiment. Both preservatives are designated in JIS K 1570 (Japanese Standards Association 2004).

The solution uptakes were thought to be varied with the density profile, permeability, and glue-line interaction of wood-based composites. Water uptakes were preliminarily determined so that the parent solutions were prepared with distilled water to achieve target retentions in the treated materials. The target retentions were selected according to the K1, K2, and K3 classes designated by Japanese Agricultural Standard JAS 1083 (Japanese Agricultural Standards Association 2007) for lumber: 0.65, 1.30, and 2.60 kg m^{-3} total ingredients for ACQ, and 0.25, 0.50, and 1.0 kg m^{-3} total ingredients for CA. These classes are identical to ISO use classes 1 (interior dry), 2 (interior damp), and 3 (exterior protected and unprotected from weather) (Suzuki 1995; International Organization for Standardization 2007). The pH values of the experimental solutions were approximately 9.6 and 8.8 for ACQ and CA, respectively.

2.3. Treatment

One-step vacuum impregnation was applied under ambient conditions. A glass cylinder containing wood-based composites was first evacuated as low as 6 kPa, and then a treatment solution of ACQ or CA was introduced. The evacuating and soaking durations were adjusted for the permeability of each wood-based composite type. The specimens were removed after the pressure inside the glass cylinder went down to the ambient atmospheric level. The retention values of ACQ and CA were calculated from the difference in mass of each treated material before and after treatment. Details of the treatment schedules are described and available in previous articles (Tascioglu and Tsunoda 2010a; Tascioglu and Tsunoda 2010b).

Nineteen specimens of each composite type and retention level combination were treated once. A total of 35 charges were carried out to acquire 665 specimens, including treatment with only water. Ten specimens were chosen from the same treatment group of 19 replicates according to the target retention levels for the subsequent mechanical tests. The epoxy coatings were removed for mechanical tests after the 6 week postconditioning period under ambient conditions.

2.4. Mechanical test

All specimens were tested as simply supported beams on an Instron universal testing machine (Instron Model 4411, Norwood, MA, USA) with third-point loading. Third-point loading was introduced as a uniform bending moment and load distribution technique that is free of shear (Khouadja et al. 1991; Kord 2012). The span was 180 mm and the crosshead speed was 10 mm min^{-1}. The failure load, MOR, MOE, and load deflection curves were recorded automatically by the testing machine's software, based on the initial input of each specimen's width and thickness. Four or 5 specimens were randomly selected from each treatment group, including untreated and water-treated controls, at the completion of each mechanical test and oven-dried at 60 ± 2 °C for the determination of moisture content (MC) at the time of testing.

An analysis of variance (ANOVA) was conducted to evaluate the effect of preservative treatments on the mechanical properties (MYSTAT 12, www.systat.com/mystatproducts.aspx).

3. Results

3.1. Retentions

ACQ and CA retentions in the treated wood-based composites are shown in Table 1. Table 2 summarizes the mean MC [MC (%)] of untreated, water-treated, and preservative-treated wood-based composites at the end of the mechanical evaluation.

3.2. Mechanical properties

The measurement data on MOR and MOE of wood-based composites are shown in Figures 1–5. The statistical analysis (ANOVA) indicated that both preservatives, ACQ and CA, had no deleterious effect on the mechanical properties of SWP at the retention levels tested. HWP, on the other hand, showed significant reductions ranging from 9.5% to 38.7% and from 19.3% to 36.1% in MOR

Table 1. ACQ and CA retentions (kg m^{-3}) in the posttreated wood-based composites as determined by solution uptake (mean of 10 replicates, numbers in parentheses are standard deviations).

Target retention (kg m^{-3})	Wood-based composites				
	SWP	HWP	MDF	OSB	PB
ACQ 0.65	0.80 (0.05)	0.70 (0.10)	0.77 (0.01)	0.67 (0.07)	0.65 (0.03)
ACQ 1.30	1.31 (0.19)	1.32 (0.15)	1.53 (0.02)	1.29 (0.09)	1.30 (0.06)
ACQ 2.60	2.65 (0.52)	2.63 (0.45)	2.99 (0.03)	2.98 (0.41)	2.58 (0.08)
CA 0.25	0.26 (0.04)	0.37 (0.02)	0.27 (0.00)	0.24 (0.04)	0.29 (0.00)
CA 0.50	0.54 (0.10)	0.72 (0.03)	0.54 (0.01)	0.48 (0.11)	0.57 (0.01)
CA 1.00	1.02 (0.24)	1.51 (0.14)	1.03 (0.01)	1.00 (0.10)	1.17 (0.01)

Table 2. Mean moisture contents (%) of untreated, water-treated, and preservative-treated composites at the time of mechanical tests (mean of 4 specimens, numbers in parentheses are standard deviations).

Wood-based composites	Treatments			
	Untreated	Water	ACQ*	CA*
SWP	8.72 (0.12)	7.56 (0.17)	8.97 (0.12)	8.04 (0.09)
HWP	7.93 (0.82)	8.84 (0.08)	6.72 (0.11)	10.47 (0.24)
MDF	6.84 (0.04)	6.00 (0.07)	4.82 (0.09)	8.45 (0.10)
OSB	6.84 (0.21)	7.30 (0.07)	9.59 (0.92)	10.50 (0.36)
PB	7.25 (0.12)	6.53 (0.10)	7.80 (0.17)	9.34 (0.16)

*Mean value of 3 retentions.

and MOE, respectively. When untreated and water-treated composites were compared, no significant reductions were recorded.

The MOR and MOE values of posttreated MDF were negatively affected by the ACQ and CA retention levels tested. Water treatment caused reductions of about 7.9% in MOR and 4.5% in MOE. The highest reductions for MDF were recorded for specimens posttreated with CA (15.4%, 9.1%, and 9.4% reductions in MOR). However, the increased reductions in MOR and MOE were not in order with the increased retention of CA (Figure 3).

Figure 4 indicates the most dramatic bending property losses for posttreated OSB material treated with the same chemical (CA) at different retention levels, with losses of up to 56.7% in MOR and 63% in MOE. According to the statistical analysis (ANOVA), there was a significant difference between untreated and water-treated material, but there were no significant differences among ACQ (P =

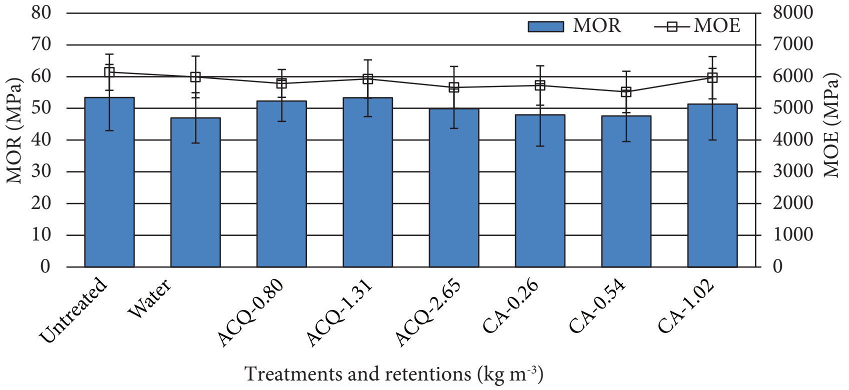

Figure 1. Effects of ACQ and CA treatments on mechanical properties (MOR and MOE) of posttreated SWP (mean of 10 replicates, error bars indicate ±standard deviations).

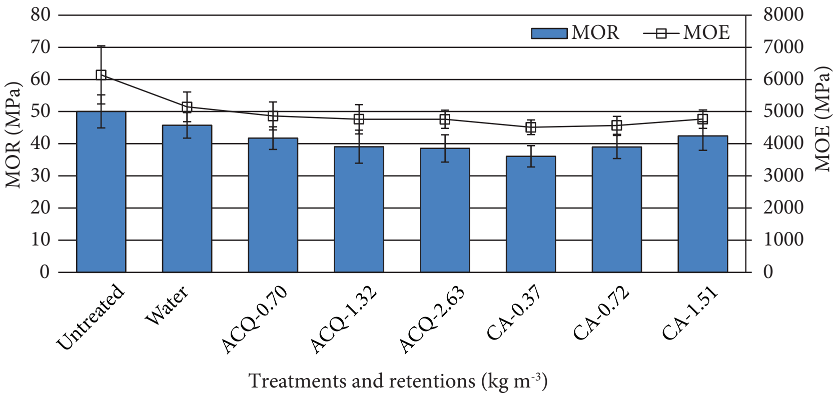

Figure 2. Effects of ACQ and CA treatments on mechanical properties (MOE and MOR) of posttreated HWP (mean of 10 replicates, error bars indicate ±standard deviations).

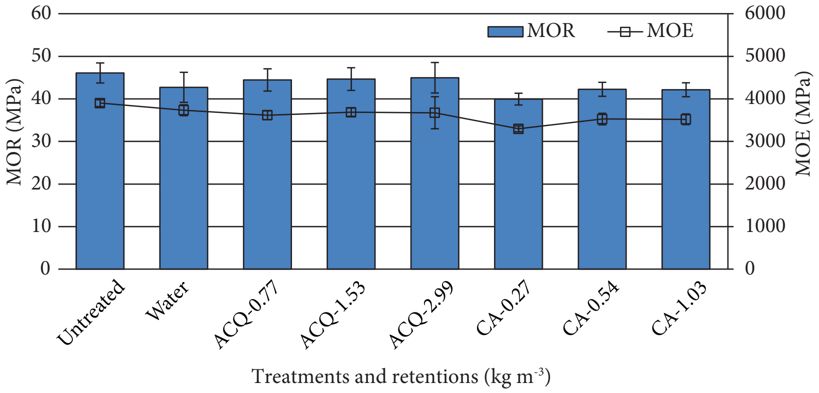

Figure 3. Effects of ACQ and CA treatments on mechanical properties (MOE and MOR) of posttreated MDF (mean of 10 replicates, error bars indicate ±standard deviations).

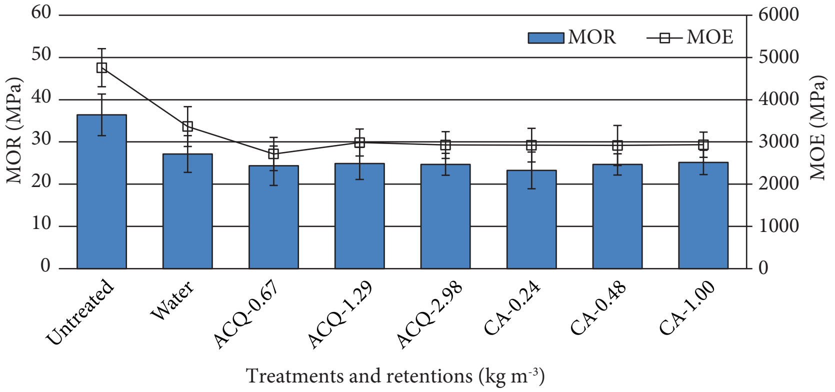

Figure 4. Effects of ACQ and CA treatments on mechanical properties (MOE and MOR) of posttreated OSB (mean of 10 replicates, error bars indicate ±standard deviations).

0.949) and CA (P = 0.418) retention groups, an indication that property reductions were unaffected by preservative retentions at the tested levels.

According to Figure 5, the posttreated PB also showed reductions in bending properties, which were relatively moderate when compared to the OSB results. The highest reductions were recorded (29.0% and 30.5%) for the highest retentions of ACQ (2.58 kg m^{-3}) and CA (1.17 kg m^{-3}), respectively. While the highest retentions of both chemicals caused the highest reductions, the statistical

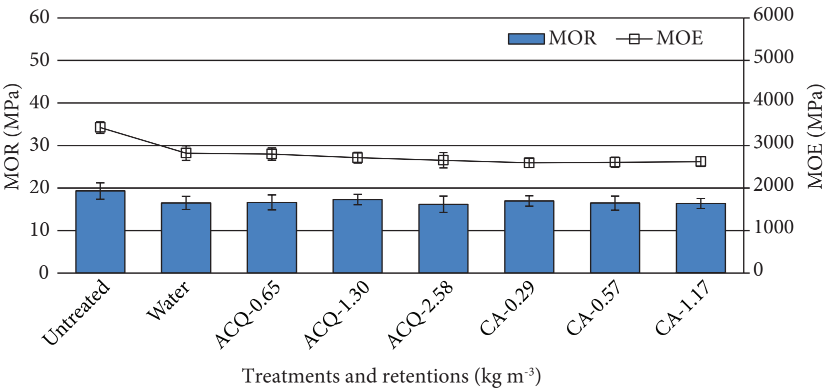

Figure 5. Effects of ACQ and CA treatments on mechanical properties (MOE and MOR) of posttreated PB (mean of 10 replicates, error bars indicate ±standard deviations).

analysis (ANOVA) did not reveal any linear correlation between the retention of ACQ and CA and MOR, with P-values of 0.341 and 0.577, respectively.

4. Discussion

The results clearly demonstrate that vacuum-soak impregnation successfully delivered both waterborne preservatives into the wood-based composites to obtain target retentions. The MC values spanned a narrow range between 5% and 10%, which indicated that all specimens had reached the adequate MC values required for mechanical testing, eliminating moisture effects on the mechanical properties (Barnes and Lindsey 2009).

Comparison of the static bending properties (MOR and MOE) of preservative-treated composites with untreated or water-treated controls generally indicated that some reduction was seen after treatment, with the exception of SWP. These corresponded well with the ACZA and ammoniacal copper arsenate posttreatments of Douglas fir plywood, which produced negligible effects on the stiffness, strength, and glue bond durability. No significant strength reduction was similarly reported for pine plywood treated with CCA at retention of 9.61 kg m^{-3} (Khouadja et al. 1991). On the contrary, a 10% loss in bending properties was recorded with Douglas fir plywood that was posttreated with CCA at 16 kg m^{-3} and subsequently air-dried (Lee 1985). When kiln drying was applied at 60 °C after posttreatment, bending properties were greatly affected, resulting in 37% and 24% reductions in MOR of aspen and Douglas fir plywoods, respectively. These reductions were more serious at the elevated drying temperature of 110 °C (Khouadja et al. 1991). Statistical comparisons among ACQ and CA retention levels did not reveal any linear relation between the increase in retentions and a decrease in mechanical properties (Figure 2).

Relatively higher mechanical property reductions in OSB can be explained by the thinner strands (<1 mm) used in their manufacture and the high void content of the composite. The wood-adhesive bonds are believed to be permanently broken, since thinner strands exhibit high water absorbency, causing irreversible swelling and loss of strength (Kamke and Winandy 2008). In addition, the highly basic character of the preservative chemicals (pH 9.8 and 8.8 for ACQ and CA, respectively) may further contribute to the reduction of adhesion strength in glue lines.

As previously demonstrated, postmanufacturing treatments with the waterborne preservatives CA and ACQ were unsuitable for OSB and PB, primarily due to high thickness swelling and unexpectedly poor biological enhancement (Tascioglu and Tsunoda 2010a; Tascioglu and Tsunoda 2010b). This conclusion is also supported by the current study, since the unacceptable losses in mechanical properties were brought about by posttreatment (Figures 4 and 5). HWP was unfavorably affected in terms of mechanical strength, regardless of preservatives (Figure 2). MDF was somewhat affected by CA treatment (Figure 3), although its resistance to decay fungi and subterranean exposure was thought to be relatively high without any preservative treatment under mildly hazardous conditions (Tascioglu and Tsunoda 2010a). In contrast, there was no detrimental effect on the bending properties of SWP after the posttreatment with ACQ and CA at any retention level tested (Figure 1). However, the strength of treatment solutions and treatment schedules should be carefully selected for the practical application of posttreatments to ensure longer protection from biological attacks without any dimensional changes or loss in strength. At the same time, the reduction in bending strength should be taken into consideration when evaluating the expectancy of posttreated wood-based composites in the engineered wood and construction industries. Prescreening tests with different wood preservative systems and wood-based engineered composites should be conducted to determine the compatibility between preservative and composite systems when new chemicals or composites are developed.

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References

Barnes HM, Lindsey GB (2009) Bending properties of wood treated with a new organic preservative system. Bioresource Technol 100: 778–781.

Gardner DJ, Tascioglu C, Wålinder MEB (2003) Wood composite production. In: Wood Deterioration and Preservation: Advances in Our Changing World (Eds. B Goodell, DD Nicholas, TP Schultz). American Chemical Society, Washington, DC, pp. 399–419.

Goroyias GJ, Hale MD (2004) The mechanical and physical properties of strand boards treated with preservatives at different stages of manufacture. Wood Sci Technol 38: 93–107.

International Organization for Standardization (2007) ISO 21887. Durability of Wood and Wood-Based Products – Use Classes. ISO Copyright Office, Geneva, Switzerland.

Japanese Agricultural Standard Association (2007) Japanese Agricultural Standard JAS 1083. Lumber (Sawn Timber). Japanese Agricultural Standard Association, Tokyo, Japan.

Japanese Standards Association (2004) Japanese Industrial Standard JIS K 1570. Wood Preservatives. Japanese Standards Association, Tokyo, Japan.

Japanese Standards Association (2008) Japanese Industrial Standard JIS 5905. Fiberboards. Japanese Standards Association, Tokyo, Japan.

Kamke FA, Winandy JE (2008) Issues and concepts for making durable composites. Proceedings of the American Wood Protection Association 104: 116–124.

Khouadja A, Barnes HM, Lyon DE (1991) Properties of CCA-treated southern pine plywood after redrying. Proceedings of the American Wood Preservers' Association 91: 82–99.

Kirkpatrick JW, Barnes HM (2006) Biocide Treatment for Wood Composites – A Review. International Research Group on Wood Protection Doc. No. IRG/WP 06-40323, Stockholm, Sweden.

Kord B (2012) Effect of compatibilizer and nanolayered silicate on physical and mechanical properties of PP/bagasse composites. Turk J Agric For 36: 510–517.

Laks PE (2002) Biodegradation susceptibility of untreated engineered wood products. In: FPJ Symposium Proceedings, No. 7249, Forest Products Society, Madison, WI, USA, pp. 125–130.

Lee AWC (1985) Effect of CCA-treating and air-drying on the properties of southern pine lumber and plywood. Wood Fiber Sci 17: 178–199.

Mitchoff ME, Morrell JJ (1991) Preservative treatment of plywood panels from the Pacific Northwest. Forest Prod J 41: 11–18.

Suzuki K (1995) Environmental situations on wood preservation industries in Japan. In: Proceedings of the 3rd International Wood Preservation Symposium, Cannes-Mandelieu, France, p. 6.

Tascioglu C, Tsunoda K (2010a) Biological performance of copper-azole treated wood and wood-based composites. Holzforschung 64: 399–406.

Tascioglu C, Tsunoda K (2010b) Laboratory evaluation of wood-based composites treated with alkaline copper quat against fungal and termite attacks. Int Biodeter Biodegr 64: 683–687.