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COPPER LEACHING PERFORMANCE OF ACQ-D TREATED WOOD AFTER MEDIUM HOT AIR POST-TREATMENTS

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ABSTRACT

Chinese fir (*Cunninghamia lanceolata* Hook.) wood cubes (19×19×19 mm) treated with alkaline copper quat-type D (ACQ-D) solution were conditioned at hot air post-treatments with medium temperatures (50 and 70°C), different vacuum degrees (atmosphere: 0.02, 0.04, 0.085 MPa) and air velocities (0, 0.5, 1, 2.5 $m.s^{-1}$) to evaluate the effects of oxygen concentration and air velocity on copper leaching of ACQ-D treated wood after medium hot air post-treatments. The results showed that the lower oxygen concentration during post-treatments caused by the higher vacuum degree would hinder the copper fixation and result in more copper loss from ACQ-D treated wood. While at atmosphere pressure, a high air velocity has both positive and negative effects on copper leaching. At lower temperature of 50°C, the adverse effect exceeds the positive effect, which causes an increase in copper leaching after post-treatments with air circulation compared with post-treatments without air circulation. But at higher temperature of 70°C, the copper leaching resistance performed the best at an air velocity of 0.5 $m.s^{-1}$.

KEYWORDS: ACQ-D (alkaline copper quat-type D), hot air post-treatment, copper, leaching, oxygen concentration, air velocity.

INTRODUCTION

Today, copper compounds are one of the main biocide components in various wood preservative formulations due to their broad-spectrum activity against several wood destroying agencies, ease of analysis and their stability toward photo-degradation, especially for the restriction of CCA treated wood in the residential markets (Archer and Preston 2006, Humar and Žlindra 2007). For China, preservative-treated wood has become more and more popular in the landscaping and wooden structures. Amine copper quat-type D (ACQ-D) is one of the predominant wood preservatives at present. As a water-borne preservative, the active ingredients in its formula are vulnerable to some leaching during service. The fixation of active ingredients of water-borne preservatives to the wood substrate is extremely important, as it greatly impacts both the performance and the environment of the treated wood products. Some studies showed that medium hot air post-treatments have been proved to significantly improve the leaching resistance of copper in ACQ-D treated wood (Ung and Cooper 2005, Yu et al. 2009). The fixation process of copper in the treated wood during hot air post-treatments would be affected by many factors, such as fixation time (Ung and Cooper 2005, Humar et al. 2006), temperature (Ung and Cooper 2005, Cao and Yu 2007), retentions (Ruddick 2003, Ung and Cooper 2005), wood species (Ung and Cooper 2005, Humar et al. 2007), relative humidity in the fixation atmosphere (Yu et al. 2009) etc. Our previous study found that besides temperature and relative humidity, air circulation, which might cause the difference in heat transfer and oxygen availability around the samples, was also an important factor on copper leaching (Yu et al. 2009). Therefore, in this study, the effects of the oxygen concentration and the air velocity on copper leaching from ACQ-D treated wood after promising medium hot air post-treatments were investigated.

MATERIAL AND METHODS

Samples and treatment

Sapwood of Chinese fir (*Cunninghamia lanceolata* Hook.) with a basic relative density of 318 $kg.m^{-3}$ from Sichuan province of China was used to make wood samples. After air-drying, the lumber was cut into small cubes with dimensions of 19.0 ± 0.2 mm and stored in a conditioning room to reach an equilibrium moisture content of 9-10 %. Then the weight of the cubes was taken, and those with similar weight were selected as test samples.

The ACQ-D concentrate used in this study was about 15 % concentration (66.7 % CuO and 33.3 % didecyldimethylammonium chloride (DDAC)) produced by a local wood preservation plant. It was diluted with deionized water to the concentrations of 1.35 % and used as treating solution. The cubes were vacuum treated at 0.1 MPa for 1 h and then submerged in the treating solution for another hour. Immediately after the ACQ impregnation, samples were performed different hot air post-treatments. Data for the post-treatment are given in Tab. 1.

Tab. 1: Post-treatment conditions for ACQ-D treated samples.

Temperature (°C)	Time (h)	Vacuum degree (MPa)	Air velocity ($m.s^{-1}$)
50, 70	10	Atmosphere 0.02, 0.04, 0.085	0
50, 70	10	Atmosphere	0, 0.5, 1, 2.5

Leaching test

Samples were used after different post-treatments according to AWPA E11-09 (2009) standard. Six replicates were used for each condition and the leachate was exchanged at prescribed intervals; the first interval was 6 h and then after 24, 8 and thereafter at 48 h intervals. The leaching test lasted or a total of 14 days. After the leaching test, the blocks were air-dried, milled to powder, and then dried at 103±2°C for 24 h. 0.15 g wood powder of each replicate was weighed and digested with the acid mixture of nitric acid and perchloric acid. Then the copper content was analyzed by using atomic absorption spectroscopy (AAS).

RESULTS AND DISCUSSION

Effects of vacuum degree on copper leaching

The percentage of copper leached out and moisture content change of treated wood after different vacuum degree of hot air post-treatments without air circulation were shown in Fig. 1a and b, respectively. As noted from Fig. 1a, copper leaching increases significantly as the vacuum degree form 0.085 MPa to about atmosphere both at 50 and 70°C. Compared to the control samples without any post-treatment, the percentage of copper leaching from ACQ-D treated wood post-treated at 0.085 MPa only reduced about 10 %, however, copper leaching reduced more than 50 % for the samples post-treated at 50°C in the atmosphere conditions, and could reduce to nearly 8 % at 70°C in the atmosphere conditions. These results demonstrated that the lack of oxygen at higher vacuum degree condition could hinder the fixation process of copper and results in the higher copper loss. It is likely due to the favourable effect of oxygen during the complicated chemical fixation reactions, which promotes the oxidation of the cupric copper converted to the insoluble copper complex. It seems that oxygen concentration plays an even more important role than temperature in the fixation process of copper in the ACQ treated wood post treated in less oxygen concentration environments (higher vacuum degrees); only in environments with plenty of oxygen, the effect of temperature on copper leaching becomes significant.

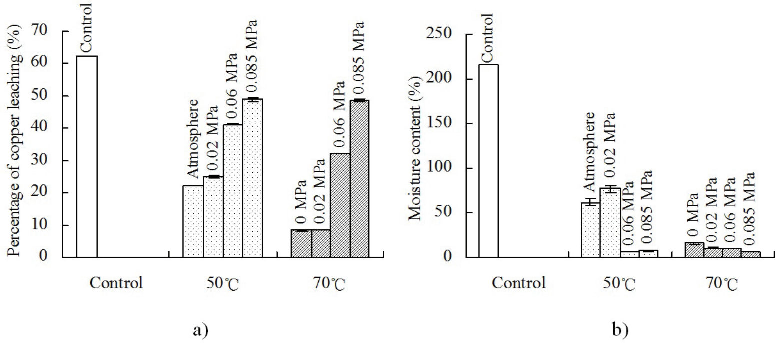

Fig. 1: Copper leaching a) and corresponding moisture content b) in ACQ-D treated Chinese fir after hot air post-treatments at different vacuum degrees.
Note: The control sample was not conditioned prior to leaching.

The other reason responsible for these results is the extremely rapid reduction of moisture content at higher vacuum degree conditions as shown in Fig. 1b. After 50°C hot air post-treatments, the moisture contents in the samples post-treated in plenty oxygen concentration environments (lower vacuum degrees) remained at the level of 60-80 %, while the moisture contents only reached to 6-8 % in the lower oxygen concentration environments (higher vacuum degrees). The similar trend could be also observed from the samples post-treated at 70°C. The lower moisture contents and fast moisture loss were responsible for the higher copper leaching, and the reasons could be included as three aspects: Firstly, the cooling effect brought by the fast water evaporation of wood has reduced the fixation temperature of the treated wood; Secondly, although higher moisture content is easily for copper leaching as the control samples, the lower moisture contents also adversely affects the copper fixation because it reduces the thermal conductivity of treated wood and delays the fixation time; Additionally, in this study, the moisture contents in the samples post-treated in the lower oxygen concentration environments (higher vacuum degrees) has dropped to lower than the fibre saturation point, and caused the fixation chemical reactions delayed or stopped. These results are confirmed by some previous investigations that too low moisture content is a negative factor for copper fixation in treated wood (Chen et al. 1994, Kaldas and Cooper 1996, Cao and Kamdem 2004).

Effects of air velocity on copper leaching

The percentage of copper leached out from ACQ-D treated Chinese fir and the moisture content after hot air post-treatments with different air velocities at atmospheric pressure were shown in Fig. 2a and b, respectively.

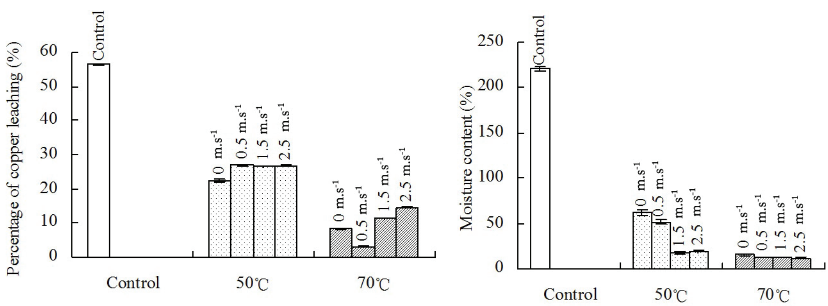

Fig. 2: Copper leaching (a) and corresponding moisture content (b) in ACQ-D treated Chinese fir after mild hot air post-treatments with different air velocities.
Note: the control sample was not conditioned prior to leaching.

From Fig. 2a, it can be seen that compared with the control samples, the hot air post-treatments used in this study could reduce copper leaching effectively, and temperature plays a significant role in this process. The copper leaching is obviously lower after post-treatments at 70°C than at 50°C. The effect of air velocity on copper leaching seems different at the two temperatures. At 50°C, the percentage of copper leached out is lower for the samples without air circulation than those with different air velocities. However, the percentages of copper leaching from all the samples post-treated with different air velocities at 50°C were changed very slightly, about 23-27 %. These results means that the samples post-treated in the plenty of oxygen environments at 50°C could obtain the similar leaching resistance and the effect of air velocities could be neglected. At 70°C, copper leaching of ACQ-D treated wood post-treated in the vacuum drying oven at an air velocity of 0.5 $m.s^{-1}$ performed the best and other samples also have better copper leaching resistance, which are attributed to the fixation environment with plenty of oxygen. The effects of a higher air velocity can be explained from two aspects, one of which is positive to copper fixation by facilitating the heat transfer in the oven, and the another is adverse because of the surface drying caused by rapid water evaporation or cooling effects on the fixation temperature inside the wood as proposed by Chen et al. (1994). At 50°C, the adverse effect of air circulation exceeds the positive effect, which finally causes the increase on copper leaching for post-treatments with air circulation. At 70°C, a suitable air velocity can accelerate the heat transfer in the treated samples and then improve the copper leaching resistance. From Fig. 2b, the moisture contents in the samples post-treated both at 70 or 50°C changed slightly, which means during hot air post-treatments with different air velocities, the effect of the moisture content is very little.

CONCLUSIONS

Oxygen concentration and air velocity in hot air post-treatments are both important factors on copper leaching for ACQ-D treated Chinese fir. The lack of oxygen and fast water evaporation at higher vacuum degree condition could definitely hinder the fixation process of copper and result in higher copper loss. However, with plenty of oxygen, the effect of air velocity seems two-sided, it could reduce copper leaching by accelerating the heat transfer in treated wood, but it could also bring in adverse effect by rapid drying and cooling effect and then increase the risk of copper leaching from ACQ-D treated wood. The balance of these two sides is related to the temperature of post-treatment. Therefore, in hot air post-treatment of ACQ-D treated wood, an adequate oxygen supply and also a suitable air velocity should be taken into consideration.

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