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MICROWAVE POST TREATMENT TO REDUCE LEACHING OF COPPER FROM ACQ TYPE C TREATED SOUTHERN YELLOW PINE

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of the requirements for the

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Major Professor's Signature

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MICROWAVE POST TREATMENT TO REDUCE LEACHING OF COPPER FROM ACQ TYPE C TREATED SOUTHERN YELLOW PINE

By

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ABSTRACT

MICROWAVE POST TREATMENT TO REDUCE LEACHING OF COPPER FROM ACQ TYPE C TREATED SOUTHERN YELLOW PINE

By

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Microwave and air dry post treatments were explored as a method to reduce the amount of copper leaching from ACQ type C preservatives treated southern pine. Southern yellow pine was pressure treated with ACQ type C, having copper elemental concentration of 0.5% and 0.8%, at an average copper retention of 3.2 kg/m^3 and 4.9 kg/^{3} respectively. After post treatments treated cube samples were subject to laboratory leaching following AWPA – E11- 97 (AWPA, 2005). Samples were subjected to three point static bending test to evaluate the effect of post treatments on bending strength in terms of modulus of elasticity (MOE) and modulus of rupture (MOR) according to modified ASTM D-143-94 (ASTM, 2005). Color change of samples before and after ACQ type C and post treatments was also measured. Microwave post treatment significantly reduced the amount of copper leaching from ACQ treated wood compared to air dry post treated samples, with 30minutes being the optimum condition for ¾ inch cubes. MOE and MOR of microwave and air dry post treated samples are not significantly different from untreated samples. Color change, ΔE, of microwave post treated samples are not significantly different from air dry post treated samples. In conclusion microwave post treatment is effective at reducing leaching of copper from ACQ type C treated southern yellow pine without reduction in bending strength and no significant color change compared to air dry post treated samples.

Dedicated to my parents, sisters and loving friends

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INTRODUCTION

Wood is used for many indoor and outdoor applications such as poles, fencing, decking, siding and walls, furniture, flooring etc. Southern yellow pine (*Pinus spp*) is widely used for decking through out the United States because of its treatability with preservative chemicals. Several species such as long leaf pine (*Pinus palustris*), short leaf pine (*Pinus echinata*), loblolly pine (*Pinus taeda*), slash pine (*Pinus elliotti*) are grouped as southern pine (Wood Hand book, 1999).

Wood is prone to decay in conditions that favor the growth of micro organisms like fungi. Wood can be made more durable by treatment with preservative chemicals. 'Preservation' is defined as treatment of wood to make it more durable (Corkhil, 1989). However some of the preservative chemicals will migrate from timber to the surroundings during outdoor exposure, known as 'leaching' (Corkhil, 1989). This includes gaseous form of chemicals emitted from treated wood, disintegration of solid form of chemical from the treated wood or the water soluble chemicals removed due to the action of water. 'Fixation' is the insolubilization mechanism that converts water soluble substances originally present in the treating solution to less soluble materials within the wood (Nicholas 1973).

Preservative treated woods are economical and durable. However, we need to ensure that chemicals used in treated wood do not harm the environment or other non target organisms. For the last three decades wood treated with chromated copper arsenate (CCA) has performed well in resisting decay and termite attack. Today there is growing public sensitivity to leaching of chemicals from treated wood and disposal of chemical

treated wood. Because of these issues CCA registrants submitted a voluntary label change to environmental protection agency (EPA). Effective since December 31, 2003 EPA label change limited the use of CCA treated wood products only for non- residential applications (Lebow, 2004). Several waterborne copper based preservatives, with no arsenic and chromium, have been formulated. Alkaline Copper Quat (ACQ), copper azole (CA), borates are listed in the book of standards of AWPA (American wood preservers association) as potential replacements for CCA. Most of the alternative preservatives use copper as active ingredient because it is a very good fungicide with low mammalian toxicity.

One of the limiting factors of amine based copper wood preservatives is the leachability of copper to the surrounding area. Studies show that up to 35% of copper in copper amine based preservative treated southern pine can be leached out (Waldron et al 2003). Stabilization of copper in the treated wood is essential to reduce the depletion of copper from treated wood to the environment.

Fixation occurs during the interaction of the ingredients of a formulation of wood preservatives and components of wood. The interaction varies with the wood species, the preservative formulation and post treatment temperature and relative humidity.

Copper undergo cation exchange reactions with wood components (Dahlgreen and Hartford, 1972; Staccioli et al, 2000). Carboxylic group in hemicellulose and the phenolic hydroxyl and ester group in lignin are the major ion exchange sites for copper during copper amine wood reaction (Jiang and Ruddick, 1999; Zhang and Kamdem ,1999; Kamdem and Zhang, 2000). Reaction between lignin guaiacyl group and copper ethanolamine to form lignin- copper- ethanolamine complexes also have been reported

(Ruddick et al 2001). Copper can complexes with cellulose matrix to form Cu (II) diamagnetic polynuclear clusters (Druz et al, 2001). Carboxylic, phenolic and hydroxylic ion exchange functionalities have different pKa values (Negative logarithm of dissociation constant). Carboxylic acid groups of hemicellulose have a pKa value of 4, phenolic groups of lignin have a pKa value of 10-12 and hydroxyl groups of cellulose have a pKa value of 13-15 (Sjöström, 1989). The different pKa value of the functional groups may suggest a certain role of pH of treating solution in influencing the ion exchange reactions between copper amine treating solution and wood. At lower pH or neutral conditions, carboxylic acid groups in wood are dissociated. Increase in pH results availability of phenolic groups for ion exchange. At very high pH, hydroxile groups provide additional ion exchange sites (Rennie *et al.*, 1987).

Copper sources, type of amine and amine to copper molar ratio of copper amine solution have been reported to affect stabilization of copper in treated wood (Zhang and Kmadem, 1999; Jiang and Ruddick, 2000; Lucas and Ruddick, 2002).

Since the number of reactive sites in wood is limited the retention of the treated wood has a major role in the stabilization and leaching of copper in copper amine treated wood. The preservative components will compete for the available reactive site in the wood. It have been reported that the amount of preservative component leaching from ACQ treated wood increases with increase in retention (Pasek, 2003; Tascioglu et al, 2005; Ung and Cooper, 2005).

Post conditioning temperature is also reported to favors fixation of copper amine based preservatives, CA and ACQ (Pasek, 2003; Tascioglu et al, 2005; Ung and Cooper, 2005). It is reported that lack of moisture in the treated sample as result of rapid drying

inhibits the ionic mobility necessary for fixation reaction (Chen et al, 1994). Higher rate and fixation extent have been reported for ACQ treated samples post treated at 50^0C compared to samples post treated at 22^0C (Ung and Cooper, 2005).

Fixation can be achieved by air drying treated wood at ambient temperature. Anderson (1990) provides an extensive review of accelerated fixation of CCA. Hot air (Kiln drying), hot water, steam, and hot oil are some accelerated fixation methods. Each method has limitations generally include longer processing time, waste water generation and potential strength reduction. Accelerated fixation methods capable of minimizing waste water generation in the case of steam or hot water and minimum strength alterations are desirable.

Electromagnetic radiations, radio waves and microwaves, were used to season and accelerate the fixation of CCA waterborne preservative and copper amine formulation in southern yellow pine (Torgovnikov and Vinden 2000, Vinden et al 2000, Smith et al 1996, Avramidis and Ruddick, 1996, Fang et al 2001, Cao and Kamdem 2004). Cao and Kamdem (2004) reported 40-45% reduction in percentage of copper leached by 20 minute microwave.

Microwave wavelength ranges from 1 cm to 1 m in the electromagnetic spectrum between radio waves and infrared waves. Microwaves can penetrate up to 2 inch thickness of wood (Smith et al, 1996). Microwave wavelength will allow energy to penetrate into wood and heat the core faster to facilitate fixation with very little drying (Smith et al 1996).

Wood with high moisture content under high temperature heating will result in discoloration as result of the formation of colored substances from the oxidation of

phenolic compound of the wood and the formation of dark material from the hydrolysis of hemicellulose and lignin (Hon and Minemura, 2000). During microwave post treatment temperature is not expected to rise more than 65^0C. So the discoloration occurs as a result of high temperature heating may not occur after microwave post treatment. Hydrolysis of hemicellulose and lignin during high temperature heating of wood can result in strength reduction. As strength reduction occu as a cumulative thermal process over time (Winandy, 1988), short time microwave may not results in strength reduction.

Even though microwave has been used as an alternative method to season and accelerate fixation of wood preservatives in the recent past, the technology is not widely used in the wood industry. No published studies have been done regarding the use of microwave to reduce the migration of copper from ACQ type C treated southern yellow pine. The aim of this project is to study the efficacy of microwave post treatment as a method to reduce leaching of copper from ACQ type C treated southern yellow pine. The impact or the effect of microwave on some properties of ACQ treated wood such as bending strength and color change will also be evaluated.

Hypothesis was formulated as follows;

During microwave energy will be generated with potential side effects; reduction in moisture content, increase in temperature, increase in rate of chemical reaction of copper with hemicellulose, lignin and cellulose of wood, chemical degradation of hemicellulose and lignin.

REVIEW OF LITERATURE

2.1 Alkaline copper quat (ACQ)

ACQ consists of copper in the form of copper oxide (CuO) and quaternarium compounds also known as quat mainly didecyldimethylammonium chloride (DDAC) or alkylbenzyldimethyl ammonium compound (BAC). AWPA standardized several ACQ formulations, ACQ type A, ACQ type B, ACQ type C and ACQ type D. The ACQ formulations are summarized in table 2.1 (AWPA, 2005).

Table 2.1 ACQ formulations

ACQ type	Active ingredients		Note
	Copper as CuO	Quat	
ACQ-A	50%	DDAC-50%	Copper content dissolved in ethanolamine and/ or ammonia to give solution having pH range of 8-11. With ethanolamine the weight of ethanolamine to copper oxide shall be 2.75± 0.25: 1, and with ammonia weight of ammonia to cooper oxide shall be 1:1
ACQ-B	66.7%	DDAC-33.3%	Ingredients dissolved in aques ammonia solution. The weight of ammonia to copper oxide in the treating solution should be 1:1.
ACQ-C	66.7%	BAC-33.3%	Copper components dissolved in ethanolamine and/or ammonia to give solution having pH 8-11. With ethanolamine the weight of ethanolamine to copper oxide shall be 2.75 ± 0.25: 1, and with ammonia weight of ammonia to copper oxide shall be 1:1.
ACQ-D	66.7 %	DDAC-33.3%	Copper content dissolved in ethanolamine and/or ammonia to give solution having pH range of 8-11. With ethanolamine the weight of ammonia to copper oxide shall be 2.75± 0.25:1, and with ammonia weight of ammonia to copper oxide shall be 1:1

2.2 Copper loss from alkali / amine copper based preservative treated wood

One of the limiting factor of new generation alkali/ amine copper based preservatives is the migration of preservative components, specifically copper, from treated wood. Leached out copper will either accumulate in soil or will percolate along with rain water to ground water system or get washed in rivers and streams. Accumulation of copper or for that matter any other heavy metals in water bodies at higher level is toxic to many aquatic organisms.

The amount of copper leached from alkali/ amine copper based preservatives, in laboratory and field conditions, have been studied by many researchers (Jin and Preston, 1993., Yamomota et al., 1999., Esser, 2000., Kennedy and Collins, 2001., Chung and Ruddick, 2003., Lucas and Ruddick, 2002., Waldron et al, 2003., Pasek, 2003).

Jin and Preston (1993) studied depletion of copper from ACQ treated southern yellow pine following laboratory leaching, soil depletion and ground contact exposure methods. They reported a 14.69% copper loss for samples treated with 6.4kg/m^3 retention from laboratory leaching test, 17.38%-17.60% copper loss for samples placed in soil bed for 3-6 months, 19% copper loss for samples exposed in Hilo, Hawaii, for 44 months as part of field stake study.

In a laboratory leaching test Lucas and Ruddick (2002) reported that copper leaching from copper monoethanolamine, having solution concentration of 0.5% and 1% (expressed as CuO), treated Scots pine is close to 15% and 25% respectively. In a similar study Cao and Kamdem (2004) reported 15% copper leaching from southern yellow pine treated with copper ethanolamine for 3.2 kg/m^3 copper retention. Later Cui at al (2005) reported a copper leaching of 5.7-18.8% from southern yellow pine cubes treated with

copper monothanolamine at copper retention varying from 2.12-5.70 kg/m^3. Waldron et al (2003) reported that almost 35% of copper available for leaching in ACQ treated southern yellow pine.

Yamamota et al (1999) studied copper leaching from ACQ treated Japanese cedar (*Chriptomera Japonica*). They reported a copper loss of 187μ g and 400 μ g per cm^3 for ACQ retention of 2.7 kg/m^3 and 5.7 kg/m3 respectively from accelerated laboratory leaching method compared to copper loss of 50 μg and 97 μg per cm^3 from outdoor leaching test for 6 months. His study shows that more preservative components are leached in accelerated laboratory leaching compared to the actual field exposure studies.

Shower test and submersion test were done by Esser et al (2000) to study the amount of copper leached from ACQ treated wood. They reported 112 mg/m^2 cumulative copper leaching after 64 days submersion test and 67 mg/m^3 after shower test.

Chung and Ruddick (2000) studied copper leaching from ACQ type C treated hem-fir used as decking by exposing 1% ACQ treated hem- fir in natural conditions for 16 months. They reported a copper leaching of 4.96% in natural conditions.

2.3 Interaction of alkali/amine based copper preservatives with wood components

Copper amine is a primary ingredient in arsenic free, copper based, new generation preservative such as ACQ and CA. Fixation chemistry of these preservatives are not well understood. Several studies were done to understand the possible interaction of active ingredients in the new generation preservatives with wood. Some of the important literature is summarized below.

Studies show that copper undergo cation exchange reaction with wood components during treatment (Dahlgreen and Hartford, 1972., Staccioli et al, 2000).

Dahlgreen and Hartford (1972) reported copper cation and chromium cation exchange reactions occur during CCA fixation. Staccioli et al (2000) did cation exchange capacity tests of copper on saponified wood and holocellulose and reported that copper behaves as bivalent cation with saponified wood and holocelloulose. They reported carboxyl group of polyoses as the major group responsible for cation exchange reactions.

The pH of the treating solution has a major role in controlling the ion exchange reactions. Carboxylic acid groups (pKa value 4) of hemicellulose are ionized in neutral or weakly acidic conditions. Phenolic groups (pKa value 10-12) of lignin are ionized at relatively higher pH. Same time hydroxyl groups (pKa value 13-15) of cellulose are ionized only in very strong base (Sjöström, 1989). Study by Pizzi (1983) shows that the amount of adsorbed copper during CCA treatment increases as the pH increases. At lower pH or neutral conditions, carboxylic acid groups in wood are dissociated. Increase in pH results availability of phenolic groups for ion exchange. At very high pH, hydroxile groups provide additional ion exchange sites (Rennie *et al.*, 1987).

Ruddick (1992) and Hughes et al (1994) did electron spin resonance (ESR) spectroscopic studies on fixation of copper amine. They suggested that copper amine complexes bound with wood through oxygen in the wood. Interaction of copper ethylenediamine solution with wood has been studied by Jiang and Ruddick (1999) using Fourier Transformed Infrared Spectroscoy (FTIR) and X-ray photoelectron spectroscopy (XPS). Their study concluded that copper react with amine and wood components during treatment, interaction of copper with wood primarily happening through carboxylic and phenolic group of wood components in agreement with Zhang and Kamdem (1999).

Solid deposits formed in copper ethanolamine treated wood was studied by Zhang and Kamdem (2000) using X-ray diffraction (XRD) technique. They concluded that copper present in its cupric form in copper amine treated wood. Later Zhang and Kamdem (2000) used Electron Paramagnetic Resonance Spectroscopy (EPR) to study the possible stereochemistry of copper complexes formed during copper amine treatment, and concluded that copper complexes in both treating solution and treated wood are in the form of CuN2O2, where copper is legated with two nitrogen and two oxygen.

Ruddick et al (2001) studied reactions of vanillin, a lignin model compound with monoethonolamine to better understand the role of guaiacyl functionality in lignin on the formation of copper amine complexes in wood using FTIR, ESR and X ray crystallographic studies and suggested that when wood is treated with ethanolamine copper solution, reaction between the lignin guaiacyl group and ethanolamine copper solution take place to form lignin- copper- ethanolamine complexes.

Druz et al (2001) studied interaction of copper with cellulose using Electron spin resonance (ESR), X-ray diffraction (XRD) and concluded that pH value of solution and light can influence the formation of copper complexes in cellulose matrix. They suggested the formation of Cu (II) diamagnetic polynuclear clusters in cellulose treated with copper solutions.

Recently Cao and Kamdem (2005) studied microdistribution of copper in copper ethanolamine treated southern yellow pine using scanning electron microscopy coupled with energy dispersive X-ray analysis in relation with the distribution of lignin, cellulose and hemicellulose in the cell wall region. They found more copper in middle lamella and cell corners compared to secondary wall of copper ethanolamine treated wood.

2.4 Factors affecting fixation and leaching of preservative chemical from treated wood

Waterborne preservatives interact with wood components during treatment. Stabilization and leaching of preservative component in wood there for varies with species, preservative formulation, post treatment conditions and the conditions during outdoor exposure. Better knowledge about the factors which determine the stabilization of preservative in the wood is pertinent to device strategies to reduce the migration of preservative components to the environment.

2.4.1 Species

Anatomical and chemical composition of wood varies from species to species. For instance softwood and hardwood differ in anatomical and chemical make up, hardwood contain less amount of lignin than softwood and their hemicellulose consists of primarily xylan pentose sugar while softwood hemicellulose contains hexose sugar (Koch, 1985). As water born wood preservatives react with wood components the stabilization reaction may vary among species.

Ung and Cooper (2005) studied stabilization of ACQ type D in different species white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), redpine (*Pinus resinosa*) and Jack pine (*P. banksiana*). The effect of species on stabilization and leaching of preservative component was minor among the species group they evaluated.

2.4.2 Source of active ingredients

Copper source, type of amine and amine to copper molar ratio and pH of treating solution will affect copper stabilization in copper amine based preservative treated wood, which in turn will affect leaching of copper from the treated wood. Effect of copper source, type of amine and amine to copper molar ratio of copper amine solution on

stabilization of copper in treated wood has been reported (Zhang and Kmadem, 1999; Jiang and Ruddick, 2000; Lucas and Ruddick, 2002).

Jiang and Ruddick (2000) compared leaching of copper 2- ethanolamine and copper ethylnediamine treated Scots pine to study the influence of different amines, 2-ethanolamine and ethylenediamine, on the fixation of copper in wood. They suggested that if the copper to amine bonding is too strong, the preservative will remain unreacted in wood and will tend to leach easily. Their study reported that copper ethylenediamine treated samples retained lower amount of copper after leaching, showing that copper insolubilisation/fixation reaction for copper ethylenediamine is less compared to copper 2-ethanolamine. They attributed this to the formation of very stable [bis(ethelenediamine)copper]$^{2+}$ cation with a very polar interaction to wood and highly basic nature of ethelynediamine. They attributed the low amount of copper leaching from copper ethanolamine on its inability to produce stable cationic species and its ability to form covalently bonded copper-amine complexes. Lucas and Ruddick (2002) also studied the effect of type of the amine on copper stabilization in treated wood. They reported a copper leaching close to 15% for Scots pine sapwood treated with 0.5% copper monoethanolamine compared to a copper leaching close to 62% for 0.5% copper ethylenediamine treated wood.

Zhang and Kamdem (1999) studied the effect of copper source, type of amine and amine to copper molar ratio of copper amine solutions on copper stabilization in treated southern yellow pine. They reported 12% copper loss from copper hydroxide systems, 10% copper carbonate, 7% from copper sulphate and 6% from copper nitrate from wood treated with 0.5% copper amine. In the same study they reported that higher molecular

weight of amine can increase copper stabilization. They reported a copper loss of 5% for tertiary amine systems compared to 12% for monethanolamine. In the same study they emphasized that increase in amine to copper molar ratio reduce the ability of copper fixation in wood and there for increase the leachability of copper in treated samples in agreement with Lucas and Ruddick (2002). An increase in copper leaching from 15% to 38% was reported by Lucas and Ruddick (2002) when amine to copper molar ratio increased from 6:1 to 8:1 in case of 0.5% copper monoethanolamine treated Scots pine.

Druze et al (2001) studied the amount of copper stabilization in cellulose treated with copper sulphate and copper carbonate at different pH. Their study shows an increase in copper adsorption in cellulose with increase in pH. They reported a copper absorption of 1-2 mg/g of cellulose at pH <2.5 compared to a copper absorption of 8-9 mg/g of cellulose at pH >8.5.

2.4.3 Retention of the treated wood

Copper amine – wood reactions are explained by ionic exchange reactions with carboxylic and phenolic groups of wood componets (Jin and Preston, 1993; Staccioli et al, 2000). Loubinoux and Malek (1992) and Loubinoux et al (1992) concluded that fixation of quaternary ammonium salts related to the number of anionic sites in wood and involve cation exchange reactions. Since the number of these reaction sites are limited copper and quaternary ammonium compounds will compete for the same reaction sites in the wood. At higher retention more preservative components are in the wood competing for the limited reactive sites. In that case some of the preservative components react with the available reactive sites and the remaining chemical remain in wood unreacted. The effect of ACQ retention on fixation and leaching has been reported. Leaching of chemical

components will be more for high retention samples when compared to low retention samples (Pasek, 2003, Tascioglu et al, 2005; Ung and Cooper, 2005).

Tasciouglu et al (2005) reported 91% and 95% adsorption of CuO in red pine treated with ACQ solution having concentration of 0.75% and post treated at 22^0C and 50^0C respectively compared to 33% and 43% for samples treated with 3% ACQ solution. It can be concluded from this study that increase in concentration of treating solution may result in higher retention at the same time will result in low amount of preservative component stabilized in the wood.

Ung and Cooper (2005) studied the copper stabilization in ACQ-D treated white spruce (*Picea glauca*), balsam fir (*Abies balsamia* L), redpine (*Pinus resinosa* Ait), Jack pine (*Pinus banksiana* Lamb), Douglas fir (*Pseudotsuga menzeissi*) and aspen (*Populous tremuloides*). Their study reported that copper stabilized much faster when lower ACQ retentions samples conditioned at 50^0C compared to high retention samples conditioned at 22^0C. They reported that high retention treatments held without drying at 22^0C took five weeks or more for copper to stabilize in wood.

2.4.4 Post conditioning temperature and relative humidity

Effect of temperature and moisture on fixation of CCA has been extensively studied by many researchers. The rate of CCA fixation is highly temperature dependent, higher the temperature, faster the fixation reaction (McNamara, 1989; Cooper and Ung, 1992; Smith et al, 1996; Cooper and Ung 1989; Cooper et al, 1997). CCA fixation time will be less for high humidity fixation compared to the fixation under drying conditions (Alexander and Cooper, 1993; Chen et al 1994). This can be explained by the fact that moisture content decreases rapidly during drying conditions. Decrease in moisture

content below fiber saturation point interfere the mobility of CCA component in the wood and decreases fixation (Kaldas, 1996., Dahlgreen and Hartford, 1972).

The effect of temperature on copper amine based preservative has been reported. It is reported that higher temperature favors fixation of copper amine based wood preservatives (Pasek, 2003; Ung and Cooper, 2005; Tascioglu et al, 2005). Tascioglu et al (2005) reported higher rate and amount of preservative fixation for ACQ treated red pine post treated at 50^0C for 7 days compared to samples post treated at 22^0C for 7 weeks. They reported CuO adsorption of 91%, 66%, 49% and 33% for redpine cubes treated with ACQ solution concentration of 0.75%, 1.5%, 2.25% and 3.00% respectively and post treated at 50^0C compared to adsorption of 95%, 88%, 64% and 43% for samples post treated at 22^0C.

Ung and Cooper (2005) studied copper stabilization in ACQ treated wood at different retentions and post conditioned at 22^0 and 50^0C. Their study reported that samples post conditioned at 50^0C took 1-5 day for copper stabilization, same time samples post conditioned at 22^0C took 4-55 days, depending on species and retention. They reported a copper leaching of 6.1-16.4% for samples stabilized at 50^0C compared to 4.8- 10.7% for samples stabilized at 22^0.

These studies show that high temperature and high moisture content is essential to achieve fixation. High temperature accelerate fixation reaction and high moisture content acts as a medium to facilitate the movement of unreacted chemical from one part of wood to other to have maximum fixation.

2.5 Microwaves - Dielectric heating effect

Microwave radiations are electromagnetic radiations with wavelength of 1 cm to 1m, and frequencies of 30 GHz to 300 MHz respectively. In electromagnetic spectrum microwaves lies in between infrared radiation and radio frequencies. Wavelength ranges of 1cm to 25cm of microwaves used for RADAR transmission and remaining range of wavelength is used for telecommunication. To avoid the conflicts with communication purposes microwave heaters are operated either at 12.2 cm (2.45GHz) or at 33.3 cm (900 MHz) unless the heater is covered to avoid radiation losses (Mingos and Baghurst, 1997).

A material capable of being heated with microwave energy is said to be polar. Polar refers to molecules have both positive and negative opposing charges (dipolar). When microwave energy field alternates from negative to positive at particular frequency results in the rotation of molecules of the material with positive and negative. The friction generated by the molecules rubbing together as they rotate generates heat (Fig 2.1).

In liquids and solids molecules are not free to rotate independently. Materials can be heated up by applying high frequency electromagnetic waves. High frequency electromagnetic waves behave like an electric field and apply force on charged particles. A current will be induced if the particles in the substances can move. If the charge carriers are restricted to certain regions they will move until an opposite force balances the movement, the result is dielectric polarization. Conduction and dielectric polarizations are source of microwave heating and the microwave heating mainly depends on frequency and power applied (Mingos and Baghurst, 1997).

Total polarization can be occurred for a dielectric material,

$\alpha_t = \alpha_e + \alpha_a + \alpha_d + \alpha_i$

Where α_e = Electronic polarization, α_a = Atomic polarization, α_d = Dipolar polarization, α_i = Interfacial polarization.

The electronic polarization is a result of the alignment of electrons around particular nuclei. Atomic polarization is due to the relative displacement of nuclei due to unequal distribution of charge within the molecule. Dipolar polarization arises from the orientation of permanent dipoles in the electric field. Interfacial polarization or Maxwell-Wagner effect occurs when there is build up of charges at interfaces. Time scale for of α_e and α_a are faster than the microwave frequencies and therefore will not contribute to the dielectric heating. At the same time scale of α_d and possibly of α_i are comparable with microwave frequencies and add to dielectric heating of microwave. Importance of α_i in microwave region is not well documented (Mingos and Baghurst, 1997).

Dipolar polarization of water is as an effect of momentum formed from the differing electro negativities of the oxygen and hydrogen. Temperature of the water hardly rises at low frequencies because the time taken by electric field to change the direction is more than the response time of the dipoles. In microwave frequency time of field change is same as the time change of dipoles. Because of the torque they experience they rotates and results in polarization lags behind the changes of electric field. The lag indicates that the water absorbs energy from the field and gets heated up (Mingos an Baghurst, 1997).

Dielectric constant, e' and dielectric loss, e'' mainly governs dielectric properties of materials. Dielectric constant is the ability of molecule to be polarized by the electric field. Dielectric loss indicates the efficiency of electromagnetic radiation can be converted to heat. The ratio of dielectric loss and dielectric constant is loss tangent, $\tan\delta$, defines the ability of a material to convert electromagnetic energy to heat energy at given temperature and frequency (Mingos an Baghurst, 1997).

Even though maximum heating is for high frequency microwaves around 20 GHz, domestic microwave oven operates at low frequency microwave at 2.45GHz to ensure heating of materials through the interior. If we are keeping the frequency for maximum heating rate (high frequency) it penetrates only the outer region.

The rate of increase of temperature due to the electric field created by microwave can be determined by the following equation.

$$\frac{\delta T}{\delta t} = \text{Constant} \times \frac{\varepsilon'' f E_{rms}^2}{\rho Cp}$$

Where E_{rms}^2 is the field intensity, ρ is the density, Cp specific heat capacity, ε'' is dielectric loss, f is frequency (Mingos an Baghurst, 1997).

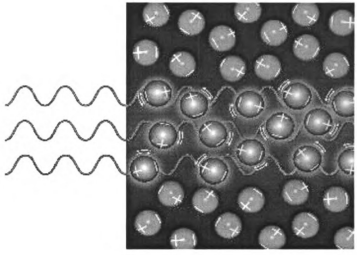

Figure 2.1 Microwave heating of dielectric material

2.6 Post treatment methods to achieve fixation

Anderson (1990) in his review paper describes kiln drying, hot water fixation and steam injection as post treatment methods to accelerate fixation of CCA in treated lumber. Feasibility of using microwaves and radio waves to accelerate fixation of CCA have been reported (Smith et al, 1996). Recently Cao and Kamdem (2004) used microwave post treatment to accelerate fixation of copper amine in southern yellow pine. These accelerated post treatment methods are discussed below.

2.6.1 Kiln drying

In kiln drying temperature and relative humidity inside the kiln is adjusted using dry bulb and wet bulb temperature. Drying schedule varies with species, the idea is to dry the lumber with less defects. Temperature limit suggested for kiln drying CCA treated southern yellow pine is 70^0C (Anderson, 1990). One of the disadvantages of kiln dried CCA treated sample is leaching of high amount of CCA components compared to air dried samples (Conardie and Pizzi, 1989; Lee et al, 1993; Chen et al, 1994).

Chen et al (1994) studied heat transfer and wood moisture effect on CCA fixation in red pine poles in different drying conditions. They observed slower fixation under drying condition. They hypothesized several possible reasons for slower fixation under drying conditions. (1) Low rate of heating of wood in a low humidity environment: Under low humidity conditions heat capacity of kiln air is lower and the heat transferred to wood surface is lower. And also under drying conditions the thermal energy reaching wood surface is used for the evaporation of water at the wood surface and is not available to get transferred in to the wood to accelerate fixation. (2) Evaporation of moisture during drying will cool the wood surface and slower fixation rate: Under dying conditions

evaporation from the surface will cool the wood in proportion to the rate of drying. Thus drier the kiln atmosphere lower the wood temperature. Since rate of fixation is depend on wood temperature not on ambient temperature (Christensen, 1990) the fixation rate will be reduced. (3) Lower moisture content of wood resulting from the drying environment may reduce fixation rate: If the wood moisture content drops the mobility of CCA reaction products in the wood may be reduced resulting in retarded fixation reactions.

2.6.2 Steaming

In this method treated samples are exposed to steam at high temperature. Steam at 110-120^{0}C for one hour is sufficient to induce complete fixation of CCA (Anderson, 1990). Steaming offers the benefits of high thermal capacity, low recycled water and low sludge formation. Higher operating temperature can degrade wood components and cause resin mobilization (Anderson, 1990). For instance in southern yellow pine resine exudation occurs above 80^{0}C causing unsightly green flecks (Anderson, 1990).

2.6.3 Hot water fixation

In this process after treatment the temperature of the lumber is raised by application of hot water either under pressure or at atmospheric pressure (Anderosn, 1990). Hot water fixation is of two types, one is MSU fixation process and the other is atmospheric pressure hot water fixation. In MSU fixation process lumber is treated by an empty cell process and the temperature of the lumber is raised by application of hot water under pressure prior to draining the excess treatment solution. In atmospheric pressure hot water fixation process hot water at atmospheric pressure in an open bath is used as the heat transfer medium.

2.6.4 Microwave heating

Dielectric heating effect of microwave to heats up polar material has been widely used in the food industry. Microwave for conditioning the wood and to achieve fixation of preservative chemicals is not a current practice in wood industry. However studies show that high temperature and high moisture content is essential to achieve fixation of waterborne preservative in wood. Moisture content of treated wood coming out of the treating cylinder is high. As microwave can heats up materials across its cross section to a high temperature very quick before substantial moisture reduction from treated wood, it can be utilized to accelerate fixation of wood preservative in wood.

Smith et al (1996) studied the feasibility of using microwaves and radio waves to accelerate the fixation of CCA components in southern yellow pine. They treated southern yellow pine with CCA for ground contact and marine use. Immediately after treatment samples were post treated using electromagnetic waves for 0, 10, 20 and 30 minutes with both RF (radio frequency) at 75MHz and microwaves at 2.45GHz. They monitored ambient fixation for 0, 0.5, 1, and 6 days. They reported that 99% of the chromium was fixed in 30 minutes of microwave. They suggested that microwaves were able to fix CCA preservative in southern yellow pine in minutes rather than hours or days.

Cao and Kamdem (2004) used microwave post treatment to reduce the amount of copper leaching from copper-ethanolamine (Cu-EA) pressure treated southern yellow pine cubes measuring 0.75 by 0.75 by 0.75 inch. In their experiment they used a microwave of 2.45GHz at a low power level of 100 watt to avoid over heating, and to lower the impact of treatment on mechanical, physical and chemical properties of treated

specimen. Their results showed that microwave post treatment reduced the amount of copper leached in samples having 6.4kg/m^3 and 3.2 kg/m^3 copper retention from 47 to 20% and 15% to 8.4% respectively after 20 minute microwave.

2.6.5 Radiofrequency (RF) heating

Radio frequency has been used to accelerate fixation of CCA in wood (Smith et al, 1996; Fang et al, 2001). Fang et al (2001) investigated the use of radio-frequency at atmospheric pressure to accelerate the fixation of CCA in Douglas –fir (*Pseudotsuga menziesi*), western red cedar (*Thuja plicata*) and red pine poles. RF heating of these species resulted in complete conversion of hexavalent chromium to the trivalent form. The fixation time was reduced to less than 5 hours with RF at 13.56 MHz.

2.7 Mechanical property of wood

Wood is an orthotropic material; that has unique and independent mechanical properties in the three mutually perpendicular axis, longitudinal radial and tangential.

2.7.1 Stress – strain relation

'Stress' is the applied force per unit area of a material. It is usually expressed in psi (lb/in^2) or in pascal (N/m^2). External force applied to a body will create internal stress resulting in deformation of the body. The deformation can be expressed as 'strain'. Strain is defined as the change in length per unit of length in the direction of the stress and is unit less. Stress – strain relation is shown in the following figure (Fig 2.4). Strain will increase proportionally with the stress applied up to the 'proportional limit' or 'elastic limit'. The region of curve below the proportional limit is called 'elastic region'. In the elastic region when the stress is removed the body can regain its original shape. Below the proportional limit the ratio of stress and strain is a constant called the

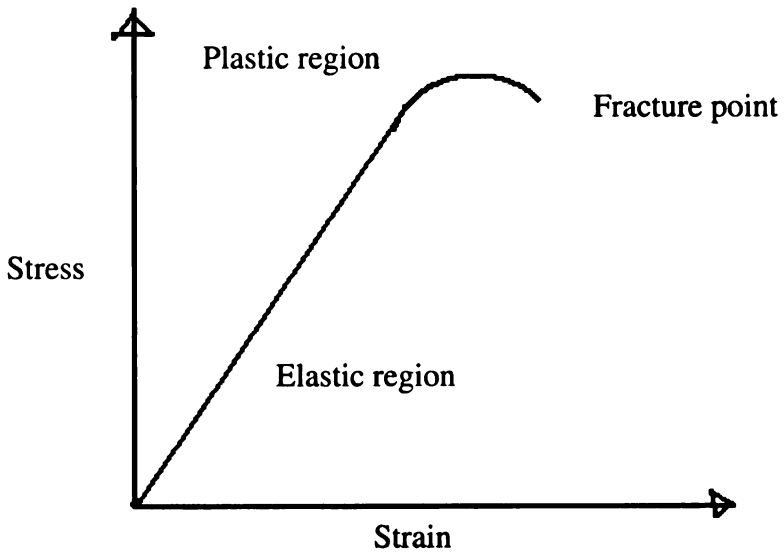

Figure 2.2 Stress- strain relations

'modulus of elasticity' (MOE). After elastic limit strain is not proportional to stress applied, each unit of stress will result in more strain than that of the strain produced below the proportion limit for a unit stress. This will continue till the 'fracture point'. Fracture point is the point where the particular material can withstand maximum stress without failure of the material. Stress after the fracture point will result in the failure of the specimen. The region of the curve from elastic limit to fracture point is called 'plastic region' (Bowyer et al, 2003).

2.7.2 Strength and elastic properties of wood

There are so many elastic and strength properties of wood discussed in the literature. Modulus of elasticity (MOE) and Modulus of elasticity parallel to grain (Young's modulus) are used to describe the elastic property of wood. Strength property of wood is described by bending strength (modulus of rupture, MOR), compression strength parallel to grain, compression perpendicular to grain, tension strength parallel to grain, shear strength parallel to grain, toughness and hardness. Wood that is strong with respect one strength property may not be strong when measuring a different property. The type of mechanical property has to be measured for a wood product is therefore determined by the type of loading to which that product will be exposed.

Modulus of elasticity (MOE): It is generally determined by use of a bending test. It reflects the stiffness and strength of long beams. MOE can be calculated by the following equation. MOE is generally expressed in psi or pascal.

$$MOE = PL^3 / 48ID$$

Where P is the concentrated centre load, D is deflection at mid span resulting from P, L is the span of the sample, I is moment of inertia a function of the beams section for beam with rectangular cross section (Bowyer et al, 2003).

$$I = \frac{w \times d^3}{12}$$

Where w is width, d is depth (Bowyer et al, 2003).

Bending strength: Modulus of rupture (MOR): It reflects the maximum load carrying capacity of wood in bending. Bending strength can be calculated by the following equation. MOR is generally expressed in psi or pascal.

$$MOR = {}^{1.5PL}\!/_{bd^2}$$

Where P is the breaking load, L span of the specimen, b width of specimen, d depth of specimen ((Bowyer et al, 2003).

2.7.3 Factors affecting mechanical property of wood:

2.7.3.1 Specific gravity

It is an excellent index of mechanical property of a species. Mechanical property within a species has a linear relationship with specific gravity (Wood Handbook, 1999).

2.7.3.2 Moisture content

Strength and elastic properties of wood increases as wood dries below fiber saturation point. This increase in mechanical property is due to the removal of water from the cell wall, which results in the pulling of long chain molecules closer and become more tightly bonded (Bowyer et al, 2003). Watkinson and Gosliga (1990) studied moisture content induced by different relative humilities on mechanical properties of hardboard, particleboard and medium density fiberboard. Their result show that 95%

relative humidity increased the moisture content to 22% and reduced MOE to 47-63%. At high relative humidity moisture content of wood will be high. Similar results were obtained by McNatt (1974).

2.7.3.3 Temperature

Mechanical properties of wood have an inverse relationship with temperature. It decreases with increasing temperature when it is heated and will decrease when it is cooled. The reduction of strength is minimum at temperature equal or less than 100^0C. Strength reduction at high temperature is cumulative thermal process over time, occurring as result of degradation of wood components at elevated temperature (Winandy, 1988). In a review paper Winandy (1988) reported 8-35% reduction in MOR in CCA treated wood exposed to elevated temperature ranging from 87^0 to 138^0C. Strength reduction occurring during high temperature heating will be more sensitive if the moisture content of wood is high (Bowyer et al, 2003).

2.7.3.4 Exposure to chemicals

Exposure of wood to severe acidic or alkaline environments can result in loss of strength from hydrolysis of cellulose, oxidation by oxidizing agents and delignification. Soft wood are more resistant to strength loss resulting from chemical exposure compared to hard wood. In general wood which are less permeable to moisture movement are resistant to chemical degradation (Bowyer et al, 2003).

2.7.3.5 Fatigue

It is the ability of material to retain its strength when subject to repeated severe loading. Strength property of wood will decrease when it is exposed to repeated loading. Repeated stress has more effect when defects such as knots are present.

2.7.3.6 Treatment with preservatives and fire retardant chemicals

Oilborne preservatives generally will not result in appreciable strength loss because they are not reacting with cell wall components. Same time most of the water based wood preservatives have some heavy metal oxides as their active ingredient and they can undergo hydrolytic reduction with sugar components of cell wall. This oxidation of cell wall components may result in strength reduction (Winandy, 1988).

However studies by Winandy et al (1985) on strength properties of CCA treated air dried southern pine showed that reduction in MOR, MOE, work to maximum load (WML) and maximum crushing strength (MCS) is not significant for samples treated with CCA retention of 0.25 – 1 pcf. They reported significant reduction in WML for southern yellow pine treated with CCA retention of 2.5 pcf.

Winandy (1988) suggested that the effect of water based preservatives on strength can be magnified if the treated wood is kiln dried at extreme conditions. Winandy (1988) reported 8-35% reduction in MOR of CCA treated wood dried at temperature range of 87-138^{0}C.

Effect of ACQ and kiln dry post treatment on MOE and MOR of southern yellow pine is reported (Barnes et al, 1993). They reported no significant difference in MOE and MOR between untreated and southern yellow pine treated with ACQ for retention of 9.6kg/m^3.

LaVan et al (1996) studied the mechanical property of fire retardant treated plywood, made of southern yellow pine, after cyclic temperature exposure. They pressure treated southern pine plywood with guanylurea/boric acid (GUP/B) and mono ammonium phosphate. They kiln dried the treated samples at 43^{0}C. After 9 days the temperature was

changed to 49^{0}C for another 7 days. Their result show that cyclic temperature exposure ranging from ambient to 65^{0}C have minimal effect on strength properties.

2.7.3.7 Conditioning and post treatment methods

Reduction in strength properties associated with the use of steaming and kin drying, to condition wood, and to post treat waterborne CCA and ACQ treated wood have been reported. (Anderson, 1990; 1987, Bendsten et al, 1983; Barnes et al, 1993). Reduction in strength properties

Collins and Vinden (1987) studied strength reduction in radiate pine after conventional steaming. They steam conditioned radiate pine in an autoclave, MOE and MOR of the steam conditioned samples were compared with control samples. Their results show losses in both MOE and MOR at fairly low steam temperature and steam times. They observed 11% loss in MOE after steaming at 115^{0}C for 1-3 hr. The loss was increased to 16% when the steaming temperature and duration was increased to 130^{0}C for 5 hr. They observed more loss in MOR after steaming. One hour steaming at 115^{0}C resulted in 21% loss in MOR and 35% when steamed at 130^{0}C for 5 hr.

Bendsten et al (1983) evaluated bending properties of longleaf pine treated with water borne ammonical copper arsenate (ACA), CCA type A, CCA type B at retentions ranging from 0.25 pcf to 2.5 pcf. After treatment they let the samples either to be air dried at 80^{0}F or kiln dried at 140^{0}F. Their results show that for all materials kiln dried after treatment MOR decreased with increasing retentions for all preservatives.

Barnes et al (1993) reported reduction in MOR of southern yellow pine treated with ACQ for retention of 9.6kg/m^3 and kiln dried at 71^{0}C compared to the untreated samples.

MATERIALS AND METHODS

3.1 Summary of the experimental procedure

Defect free southern yellow pine was selected to prepare required sample size for leaching, strength and color property studies. Samples were conditioned at 21^0C and 65% relative humidity to an equilibrium moisture content of 10 ± 2%. Conditioned samples were treated with ACQ type C and subjected to two post treatments air drying and micro waving at different durations. After post treatments samples for leaching study were subjected to leaching to study the amount of copper leaching from different post treated southern yellow pine according to AWPA-E11-97 standard (AWPA, 2005). Samples were subjected three point static bending test to evaluate the effect of post treatments on bending strength in terms of MOE (Modulus of elasticity) and MOR (Modulus of rupture) according to ASTM-143-94 standard (ASTM D, 2004). Color change of samples before and after ACQ type C and post treatments were also measured. Data obtained for leaching, strength change, and color change after post treatments were analyzed.

3.2 Specimen preparation

3.2.1 *Specimen preparation for leaching study*

Specimens measuring 19 by 19 by 19 ± 0.2 mm were prepared according to the sample preparation described for laboratory leaching in AWPA-E11-97 standard (AWPA, 2005). Samples were taken from one board of southern yellow pine having a specific gravity of 0.5 to reduce the board to board density variation. Samples with similar density were selected for the study.

3.2.2 *Specimen preparation for static bending test: For non-destructive MOE and Destructive MOE and MOR*

Samples were prepared southern yellow pine sap wood board having a specific gravity of 0.54 according to specimen preparation described for three point static bending of clear specimen in the ASTM D-143-94 standard (ASTM, 2005) with a modification in sample size. Flat sawn samples measuring 1.27 by 1.27 by 22.86 cm (.5 by .5 by 9 inch) were prepared, keeping a span to depth ratio of 14, specified in the standard. Sample size was reduced to facilitate easy rotation during microwave post treatment to achieve even heating of the samples.

3.2.3 *Specimen preparation to study color change*

The specimen size measuring 0.5 by 7 by 10 cm was prepared to study color change.

3.3 Preparation of ACQ type C treating solution

NW 100 with a copper elemental concentration of 7.4% was received from OSMOSE. Stock solution received was diluted for ACQ type C formulation having copper elemental concentration of 0.5% and 0.8%.

3.4 pH of the treating solution

pH of the treating solution was measured using pH meter Consort-P601.

3.5 Pressure treatment of samples using ACQ type C

Samples conditioned for equilibrium moisture content were pressure treated with ACQ type C in a cylindrical tank having a radius of 15.2 cm (6 inch) and a length of 47 cm (18.5 inch) using an initial vacuum of 84.6 KPa (25 inch mercury) for duration of 20 minutes and a pressure of 1034 KPa (150 Psi) for 60 minutes following a final vacuum

for 20 minutes. Samples were weighed before and after treatment to determine solution pick up.

3.6 Retention (kg/m^3)

Copper retention of the ACQ type C treated sample was calculated using following equation

$$\text{Copper (Cu) retention } (kg/m^3) = \frac{WG \times C \times 10}{V}$$

Where (WG), weight gain of the sample in grams after treatment $= W2 - W1$, $W1$ is weight of the sample in grams before the treatment, $W2$ is weight of the sample in grams after treatment, C is weight of copper grams in 100g treating solution, V is volume of the sample in cm^3 or ml.

$$\text{Copper oxide (CuO) retention } (kg/m^3) = \frac{WG \times C \times 10}{V} \times 1.25$$

$$\text{ACQ type C retention } (kg/m^3) = \frac{WG \times C \times 10 \times 1.25}{V \times .667}$$

Note: Molecular weight of Cu: CuO = 1: 1.25

Weight CuO: ACQ type C = 0.667: 1

3.7 Initial copper content in leaching blocks

Initial copper content in each block was calculated using the solution pick up (weight gain after treatment) and concentration of treating solution using the following equation.

$$\text{Initial copper content (mg)} = WG \times C \times 1000$$

Where WG is weight gain after treatment (solution pick up) in grams, C is concentration of treating solution in %.

3.8 Microwave post treatment

Samples were subjected to microwave post treatment in a Gold star multiwave microwave oven with a frequency of 2.45 G Hz and a power level of 100W for duration of 0, 10, 20 and 30 minutes (Smith et al, 1996; Cao and Kamdem 2004) Microwave was done at low power (100W) to avoid over heating. Weight of the samples before and after post treatment and dry weight of the corresponding samples were used to calculate the moisture content after post treatment.

High performance non contact thermometer model MX4 from Raynger (Raytek, Sata Cruz, CA, USA) was used to monitor surface temperature of samples during microwave post treatments.

3.9 Air drying post treatment

After ACQ type C treatment samples were kept in a room set at 21^0C (70^0F) and 65% relative humidity. Air drying was continued for 21 days.

3.10 Leaching of post treated samples

One hundred and sixty samples were prepared for this study. Samples were weighed and grouped in to 2 groups of 80 samples and pressure treated with ACQ type C having copper concentration of 0.5% and 0.8%. After ACQ treatment group of 80 samples were divided into 5 small groups of 15 samples each and subjected to post treatments. The remaining 5 samples were used for acid digestion.

Three out of 15 samples from each post treatment group was randomly selected for further chemical analysis if needed. The remaining 12 samples of each post treatments were subjected to leaching according to the method described for laboratory leaching in

AWPA-E11-97 (AWPA, 2005). Copper content in the leachate collected during 0, 6, 24, 48 hours then after every 48 hours of the leaching study was measured using Perkin Elmer 3110 Atomic absorption spectrometer. The amount of copper leached to the 300 ml water was calculated using the following equation.

Copper content in 300 ml leachate (mg) = $AA \times DF \times 0.3$

Where AA is atomic Absorption reading (mg/l), DF, dilution factor, which is the ratio of final volume to initial volume during dilution.

Cumulative copper leached in % (compared to the initial copper content) was further calculated. Percentage of copper leached from different post treatment groups, after 14 days of leaching were compared.

3.11 Static bending strength

3.11.1 Non destructive method to calculate MOE

For this particular study load required making a displacement of 0.19 cm (.075 inch) (Below the proportional limit) on each of the samples were measured before treatment using Universal testing machine, Instron model No -4206, following the procedure described in the ASTM D-143-94 (2004) for three point static bending. MOE of each sample was further calculated, from the load and displacement measurement, using the following equation.

$$MOE = PL^3 / 48ID$$

Where P is the concentrated centre load, D is deflection at mid span resulting from P, L is the span of the sample, I is moment of inertia a function of the beams section for beam with rectangular cross section (Bowyer et al, 2003).

$$I = \frac{w \times d^3}{12}$$

Where w is width, d is depth (Bowyer et al, 2003).

Load required making the same displacement after post treatments were measured on the same position of the sample to study any change in MOE after post treatment.

One hundred and twenty samples were prepared and conditioned. Load required to make a displacement of 0.19 cm (.075 inch) was measured on each sample to calculate MOE. Samples were grouped into 2 groups of 60 samples and treated with ACQ type C having elemental copper of 0.5% and 0.8%. After ACQ type C treatment each treatment group of 60 samples were divided in to 4 small groups of 15 samples each and subjected to post treatments. After the post treatment samples were conditioned. Load required to have the same of 0.19 cm (.075 inch) was measured using Universal testing machine, Instron (Model No: 4206).

3.11.2 Destructive method for MOE and MOR

The samples used for non destructive method to calculate MOE were further used to measure MOE and MOR using Universal testing machine, Instron (Model-4206) following the procedure described in the ASTM D-143-94 (2004) for the three point bending of clear samples with the specimen size modification described in the earlier section. Load was applied upto failure to measure MOE and MOR. MOE and MOR obtained for the post treated samples were compared with 15 control samples (without ACQ type C treatment and post treatments).

3.12 Color change

Twenty samples each were treated with ACQ type C having copper elemental of 0.5% and 0.8%. Samples were divided in to 5 groups of 4 after ACQ treatment and

subjected to post treatment. Color change of the wood surface before and after post treatment was determined according to ISO 2470 standard (Anonymous 1999) using a Micro flash Elrepho model 200 Reflectrometer from Data Color International, Charlotte, NC with CIELAB system. The CIELAB system is characterized by three color parameters 'L', 'a' and 'b. The '*L*' axis represent the lightness, 'a' and 'b' are the chromaticity co-ordinates. In the CIELAB co- ordinate '+a' is for red, '-a' is for green, '+b' for yellow, '-b' for blue. '*L*' varies from 100 (white) to 0 (black). These values were used to calculate color change (ΔE), using the following equations.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

$$\Delta L = L_f - L_i$$

$$\Delta a = a_f - a_i$$

$$\Delta b = b_f - b_i$$

Where L_f, a_f, b_f are final values of lightness L and chroma 'a' and 'b'

L_i, a_i, b_i are initial lightness L and chroma 'a' and 'b'

Average of 5 readings per sample was taken for this study.

Color change after post treatments were compared to study the effect of post treatment in color change.

3.13 Data analysis

A factorial experimental design with post treatment, at different levels, and ACQ retention at two levels as factors was used for this study. Data was analyzed using factorial analysis of variance (ANOVA). Residual diagnostics was performed to check for the fulfillment of the ANOVA assumptions and eventually to select appropriate data transformations. Interaction between post treatment and ACQ type C retention were studied as a primary step. Post treatments were compared either grouping the post treatment results for different retentions (if the interaction is insignificant) or keeping them separate (if the interaction is significant). Multiple comparisons were done where it was relevant.

RESULTS AND DISCUSSION

4.1 Retention

ACQ type C treating solutions having copper elemental concentration 0.5% and 0.8% had a pH of 9.3 ± 0.1. Samples pressure treated with both the treating solutions were observed to have good solution pick up close to 100%. Average copper retention calculated for samples treated with 0.5% copper elemental ACQ type C was 3.2 kg/m^3. This corresponds to an average CuO retention of 4 kg/m^3 and ACQ retention of 6 kg/m^3. Samples treated with 0.8% copper elemental ACQ type C had an average copper retention of 4.9 kg/m^3, which corresponds for an average CuO retention of 6.1 kg/m^3 and ACQ retention of 9.2 kg/m^3.

4.2 Microwave and air dry post treatments

Temperature and moisture content change during microwave and air dry post treatments were summarized in table 4.1. Surface temperature of the samples before post treatment was about 19^0C. A rapid increase in surface temperature of the samples was observed during microwave post treatment. Surface temperature of the post treated samples increased to a maximum of 64- 70^0C, even with 10 minutes of microwave. Not much change in surface temperature was observed with 20 and 30 minutes microwave post treatment. Treated samples had an average moisture content of 115% immediately after treatment, but this moisture content observed to decrease during microwave post treatment. Moisture content of the samples reduced to 72%, 30% and 13% respectively after 10, 20 and 30 minutes of microwave. The moisture content of air dried samples

reduced to 9.5 % after 21 days. Surface temperature of the samples after 21 days of air drying post treatment was the same as before the post treatment.

4.3 Leaching – Effect of microwave and air dry post treatment

Initial copper content in the blocks used for leaching calculated based on solution pick up and concentration of copper in the treating solutions were summarized in table 4.2 and detailed in appendix table 1-2. Total initial copper content in the leaching blocks (6 blocks) observed to vary from 126-143 mg and 195-219 mg respectively for 0.5% (3.2 kg/m^3 copper retention) and 0.8% (4.9 kg/m^3 copper retention) copper elemental ACQ type D treated samples.

Cumulative copper leached over different leaching durations up to 336 hours of leaching is summarized in table 4.3, 4.5 and figure 4.1, 4.3. Results shows that copper is leached to surrounding water medium over time by the action of water, indicating the amount of un-reacted copper in the post treated samples. Irrespective of the retention and post treatment maximum amount of copper is observed to leach out during initial 48 hours of leaching.

Percentage of copper leached during different intervals of leaching experiment, calculated based on initial copper content and the cumulative copper leached during the corresponding leaching duration, is summarized in table 4.4, 4.6 and figure 4.2, 4.4 and detailed in appendix table 3-12. Results show that irrespective of the retention and post treatment major share of the total percentage of copper leached after 336 hours of leaching is occurred within 48 hours (Table 4.4, 4.6, Figure 4.2, 4.4).

Percentage of copper leached out from the samples treated with 0.8% copper ACQ, having a copper retention of 4.9 kg/m^3 was higher than that of the samples treated

with 0.5% copper ACQ having a copper retention of 3.2 kg/m^3 in all the post treatment groups. The percentage of copper leached out, from the samples treated with 0.5% copper ACQ for a copper retention of 3.2 kg/m^3, after 336 hr leaching were 33, 27, 17, 13 and 17 respectively for 0 minutes microwave, 10 minutes microwave, 20 minutes microwave, 30 minutes microwave and 21 days air dry post treatments, compared to 42, 32, 30, 19 and 22 for the samples treated with 0.8% copper ACQ for a copper retention of 4.9 kg/m^3 copper. Results show that retention of the treated samples has a significant effect ($P<0.001$) in the percentage of copper leaching from southern yellow pine treated with ACQ type D in agreement with the studies of Pasek (2003), Tascioglu et al (2005) and Ung and Cooper (2005).

Copper amine based preservatives and wood interactions, mainly ion exchange reactions between copper complexes and quaternary ammonium salts in the preservative solution and wood depends on the number of anionic sites in wood (Jin and Preston, 1991; Staccioli et al, 2000., Loubinoux and Malek, 1992 and Loubinoux et al, 1992). Since the number of these reaction sites in the wood is limited copper complexes and quaternary ammonium compounds will compete for the same reaction sites in the wood. In case of samples treated with ACQ type C for a copper retention of 4.9 kg/m^3 the competition of preservative components for the available reaction sites will be much higher compared to the samples treated for a copper retention of 3.2 kg/m^3. Some of the preservative components in the wood will react with the reaction sites close to it; some other may migrate to other part of the wood, if there is enough moisture to facilitate ionic mobility (Chen et al, 1994), and the remaining unreacted preservative components may get physically deposited in the wood as the treated wood get dried. Unreacted

preservative components will get leached out when treated wood come in contact with water. The amount of unreacted preservative components will be higher in samples treated for higher retention. This can be the reason for the higher percentage of copper leaching from samples treated for a copper retention of 4.9 kg/m^3 compared to samples treated for a copper retention of 3.2 kg/m^3.

For samples treated with ACQ solution having an elemental copper of 0.5% thirty minutes microwave reduced leaching to 13% compared to 17% for air dry post treated samples. At the same time for samples treated with ACQ having an elemental copper 0.8% thirty minutes microwave reduced leaching up to 19% compared to 22% for air dries samples (Table 4.4, 4.6, figure 4.2, 4.4). In both the case the difference was statistically significant. Result shows a significant decrease ($P<0.001$) in the percentage of copper leached with an increase in microwave duration for both retention levels (Table 4.4, 4.6, fig 4.2, 4.4), indicating the effect of microwave to reduce the depletion of copper within 30 minutes of microwave. Same trend was reported by Jinzhen and Cao (2004). There was an overall significant difference in percentage of copper leached from microwave and air dry post treated samples ($P<0.001$). Lower percentage of copper leaching observed for thirty minute microwave post treated samples compared to air dried samples shows that the amount of copper stabilized in thirty minute microwave post treated sample is higher than that of air dried samples. This can be due to rapid increase in temperature (up to 64-70^{0}C) during microwave post treatment before the moisture content drops down to 13% after 30 minute microwave (Table 4.1). Increase in temperature will accelerate the ion exchange reaction of preservative components with wood; in that case stabilization of copper in the wood will be higher.

Table 4.1 Temperature and moisture content of post treated samples

Post treatment	Average moisture content after ACQ treatment (%)	Temperature of wood sample after ACQ treatment (^{0}C)	Moisture content after post treatment (%)	Surface temperature at the end of post treatment (^{0}C)
M10	115	19	72	64-70
M20			30	
M30			13	
A			9.5	19

Note: Legend description in figures and tables: M0, M10, M20 and M30 represent microwave post treatment for different duration of 0 minute, 10 minutes, 20 minutes and 30 minutes. A is air dry post treatment for 21 days.

Table 4.2 Initial copper content in six blocks used for leaching

Treating solution concentration	Average retention (kg/m^3)			Post treatment	Rep	Initial copper content in 6 leaching blocks (mg)
	Cu	CuO	ACQ			
0.5% Cu	3.2	4	6	M0	1	137.45
				M0	2	126.65
				M10	1	137.70
				M10	2	126.50
				M20	1	133.90
				M20	2	142.80
				M30	1	138.15
				M30	2	133.55
				A	1	134.60
				A	2	131.30
0.8% Cu	4.9	6.1	9.2	M0	1	200.72
				M0	2	206.16
				M10	1	211.04
				M10	2	212.80
				M20	1	212.16
				M20	2	215.52
				M30	1	218.80
				M30	2	217.36
				A	1	196.72
				A	2	195.12

Where M0, M10, M20 and M30 represent microwaving post treatment for different duration of 0 minute, 10 minutes, 20 minutes and 30 minutes. A is air dry post treatment.

Table 4.3 Average cumulative copper leached from post treated southern yellow pine, treated with ACQ type C, having 0.5% Cu elemental, for a copper retention of 3.2 kg/m^3

Duaration(h)	Cumulative copper leached (mg)				
	M0	M10	M20	M30	A
6	37.52	22.53	11.73	8.11	11.86
24	41.74	30.48	19.43	13.25	16.62
48	42.88	33.55	21.16	14.25	19.17
96	43.18	34.19	21.96	15.58	20.65
144	43.38	34.77	22.79	16.73	21.21
192	43.50	34.99	22.96	16.93	21.74
240	43.57	35.09	23.17	17.06	21.88
288	43.67	35.26	23.35	17.25	22.07
336	43.74	35.42	23.61	17.46	22.18

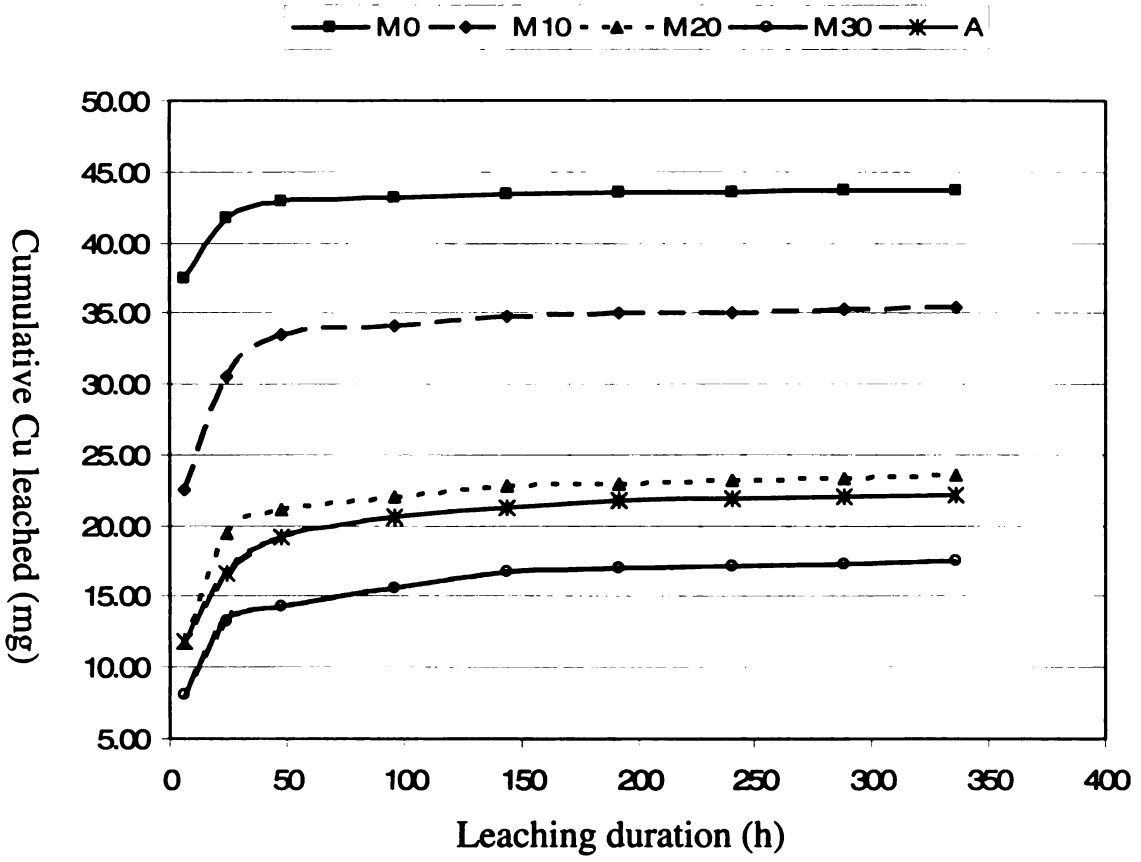

Figure 4.1 Average cumulative copper leached from post treated southern yellow pine, treated with ACQ type C, having 0.5% Cu elemental, for a copper retention of 3.2 kg/m^3

Table 4.4 Percentage of copper leached from post treated southern yellow pine treated with ACQ type C, having Cu elemental 0.5%, for a copper retention of 3.2 kg/m^3

Duration (h)	% Cu leached				
	M 0	M 10	M 20	M 30	A
6	28	17	8	6	9
24	32	23	14	10	12
48	32	25	15	10	14
96	33	26	16	11	16
144	33	26	16	12	16
192	33	26	17	12	16
240	33	27	17	13	16
288	33	27	17	13	17
336	33	27	17	13	17

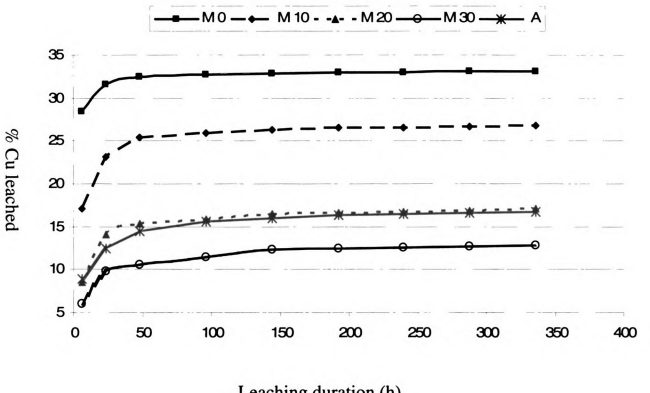

Figure 4.2 Percentage of copper leached from post treated southern yellow pine treated with ACQ type C, having Cu elemental 0.5%, for a copper retention of 3.2 kg/m^3

Table 4.5 Average cumulative copper leached from post treated southern yellow pine, treated with ACQ type C, having 0.8% Cu elemental, for a copper retention of 4.9 kg/m^3

Duration (h)	Cumulative copper leached (mg)				
	M0	M10	M20	M30	A
6	51.60	42.27	41.56	22.67	21.95
24	74.46	57.60	53.59	32.47	33.39
48	80.68	63.73	59.58	37.29	37.13
96	83.56	66.60	62.87	40.17	39.98
144	84.31	67.44	63.94	41.23	41.38
192	84.64	67.78	64.36	41.75	42.17
240	84.89	68.00	64.65	42.08	42.80
288	85.09	68.21	64.88	42.34	43.45
336	85.26	68.38	65.07	42.53	43.94

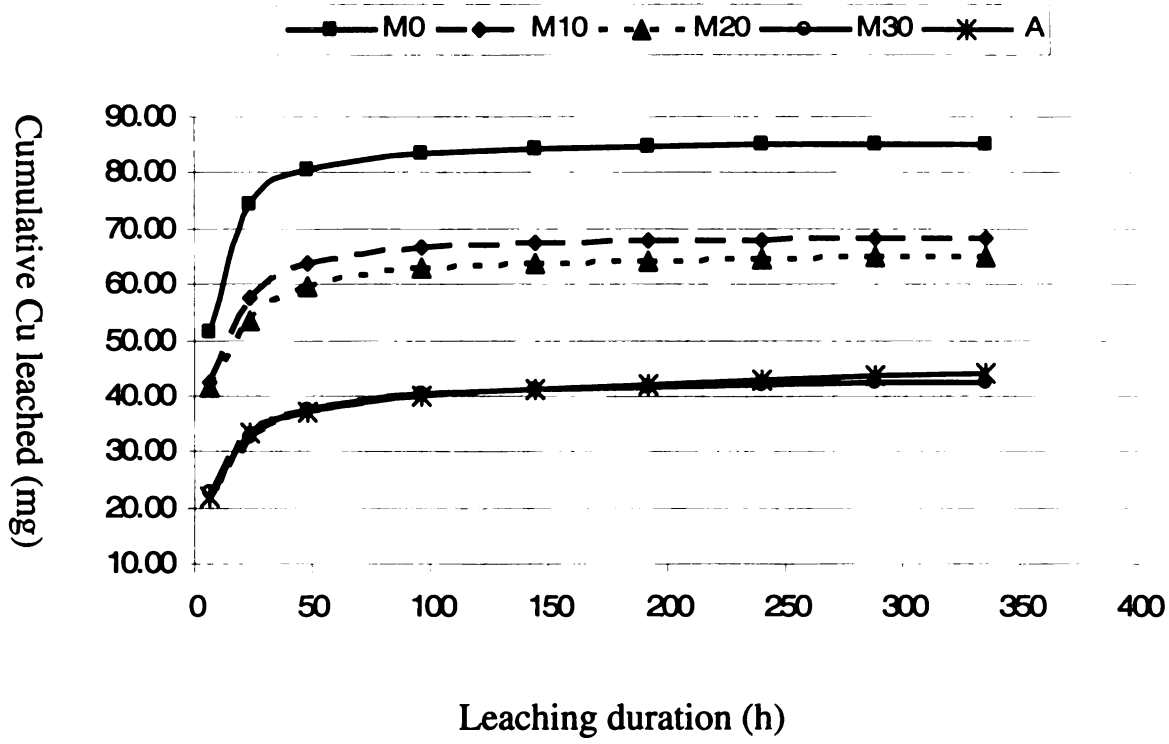

Figure 4.3 Average cumulative copper leached from post treated southern yellow pine, treated with ACQ type C, having 0.8% Cu elemental, for a copper retention of 4.9 kg/m^3

Table 4.6 Percentage of copper leached from post treated southern yellow pine treated with ACQ type C, having Cu elemental 0.8%, for a copper retention of 4.9 kg/m^3

Duration (h)	% Copper leached				
	M0	M10	M20	M30	A
6	25	20	19	10	11
24	37	27	25	15	17
48	40	30	28	17	19
96	41	31	29	18	20
144	41	32	30	19	21
192	42	32	30	19	22
240	42	32	30	19	22
288	42	32	30	19	22
336	42	32	30	19	22

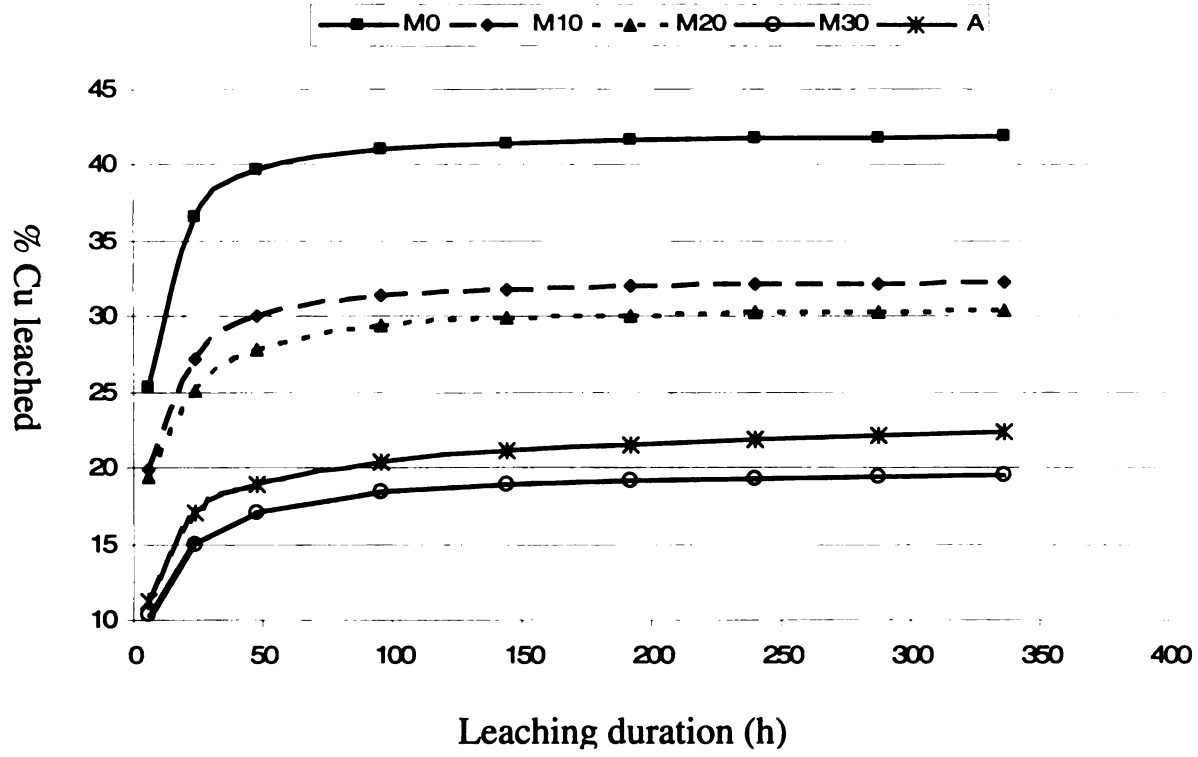

Figure 4.4 Percentage of copper leached from post treated southern yellow pine treated with ACQ type C, having Cu elemental 0.8%, for a copper retention of 4.9 kg/m^3

4.4 Mechanical properties – MOE and MOR

4.4.1 Non destructive MOE

MOE calculation before and after are detailed in appendix table 13 and summarized in table 4.7 and figure 4.5, 4.6. Results shows an increase of 5-8% in MOE for all microwave post treatment for different durations of 10, 20 and 30 minutes and air drying post treatment for 21 days. MOE of 0.5% ACQ treated 30 minute post microwave treated samples increased from 7663 MPa to 8064 MPa compared to an increase from 7456 MPa to 7833 MPa for 0.8% ACQ treated 30 minute microwave post treated samples. Same time MOE of 0.5% ACQ treated air dried samples showed an increase from 7878 MPa to 8303 M Pa compared to an increase from 7456 MPa to 7833 MPa for 0.8% ACQ treated air dried samples. But the observed increase in MOE cannot be attributed as a result of post treatment as the errors to measure the load required to make the displacement of 0.19 cm from the sample after post treatment, from exactly the same position, are highly probable while using Instron. No decrease in MOE was observed either for samples microwave post treated at different durations or for air dried samples. These results suggests that short term micro waving up to 30 minuets at 100W is not resulting in any thermal degradation of wood components such as cellulose and lignin to cause any reduction in elasticity of southern yellow pine in agreement with the fact that strength reduction is cumulative thermal process over time (Winandy, 1988).

4.4.2 Destructive MOE

Destructive MOE of southern yellow pine samples subjected to different post treatments and control samples are summarized in table 4.8 and figure. 4.7and detailed in appendix table 14.

Southern yellow pine samples, neither treated with ACQ type C nor any post treatments, shows an average MOE of 10040 M Pa in Universal Testing machine. ACQ type C, having copper elemental concentration of 0.5% and 0.8%, treated air dried samples was observed with MOE of 10100 M Pa and 10150 M Pa respectively. No significant difference in MOE was observed for air dry post treated samples when compared to control samples (Pr>.3485) in agreement with the studies of Barnes et al (1993). This shows that ACQ type C treatment is not resulting in strength reduction, resulting from the hydrolysis and delignification of wood components, in southern yellow pine.

MOE of 30 minute microwave post treated southern yellow pine were 10398 M Pa and 10152 M Pa respectively for samples treated with ACQ type C having 0.5% and 0.8% Cu elemental. Results shows that MOE of 30 minute microwave post treated samples are not significantly different from air drying post treated and control samples (Pr>0.3485).

No significant difference in MOE was observed between samples treated with ACQ type C, having 0.5% copper elemental, for a copper retention of 3.2 kg/m^3 and samples treated with ACQ type C, having 0.8% copper elemental, for a copper retention of 4.9 kg/m^3 (Pr>0.4910), irrespective of the post treatments.

4.4.3 Correlation of non-destructive and destructive MOE

MOE of post treated samples, measured non - destructively and destructively, are plotted against specific gravity in figure 4.8 and figure 4.9 respectively. Increase in MOE was observed for an increase in specific gravity for destructive and non- destructive MOE. Correlation coefficient was observed to less in both the cases. It is due to the fact that the MOE is forming a clusture across the specific gravity range (0.5- 0.58) (Figure 4.8 and Figure 4.9). Comparatively good trend was observed for destructive MOE, in agreement with the fact that mechanical strength increase as specific gravity increases. This result shows that MOE measured using destructive method is more reliable. MOE of the each sample measured after post a treatment using destructive method is plotted against MOE measured non-destructively in figure 4.10. Good correlation was observed between destructive and non-destructive MOE. This result suggests that non- destructive MOE can be effectively used for the initial sample selection, to reduce the variability in MOE, for studying the effect of treatments on mechanical property.

4.4.4 Destructive MOR

MOR of post treated and control samples were detailed in appendix table 14 and summarized in table 4.9 and figure 4.11. For control samples MOR varied from 102-104 M Pa. At the same time for post treated samples, samples treated with 0.5% (3.2 kg/m^3 copper retention) and 0.8% (4.9 kg/m^3 copper retention) copper elemental ACQ type C solution MOR varied from 102-110 M Pa.

No reduction in MOR was observed for air dry post treated samples compared to the control at both the retention levels in agreement with the Barnes et al (1993). MOR of

control sample was 102 M Pa while samples treated at a copper retention of 3.2 kg/m^3 had MOR of 104 M Pa compared to 109 M Pa for samples treated at 4.9 kg/m^3 retention.

MOR of samples treated at a copper retention of 3.2 kg/m^3 and microwave post treated for 30 minutes was 103 M Pa compared to 109 M Pa obtained for 4.9 kg/m^3 copper retention samples.

Statistical analysis shows that there is no significant difference in MOR between control and post treated samples (Pr>0.9556). This result shows that 30 minute microwave post treatment at a power level of 100W or air drying post treatment, not resulting in strength reduction in southern yellow pine. This again supports the argument that strength reduction is a cumulative thermal process over time (Winandy, 1988).

Table 4.7 Non- destructive MOE before and after ACQ type C and post treatments

Treating solution concentration	Cu retention (kg/m^3)	Post treatment	MOE before ACQ and post treatments (M Pa)		MOE after ACQ and post treatments (M Pa)		Change in MOE (%)	
			Average	stdev	Average	stdev	Average	stdev
0.5% Cu	3.2	M10	7553	453	8064	522	7	3
		M20	7972	878	8479	1035	6	3
		M30	7663	415	8174	441	7	2
		A	7878	688	8303	662	6	3
0.8% Cu	4.9	M10	7860	620	8330	818	6	3
		M20	7556	657	8061	883	7	4
		M30	7446	649	8005	637	8	3
		A	7456	486	7833	512	5	3

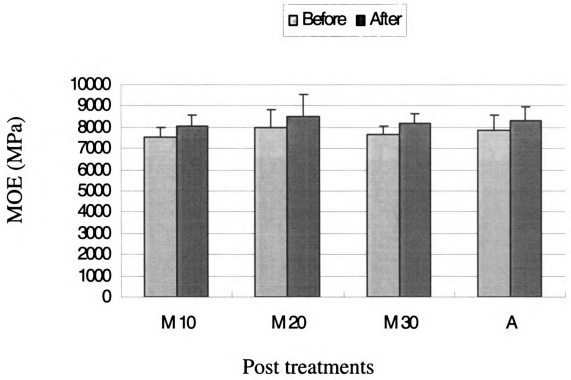

Figure 4.5 Non Destructive MOE of southern yellow pine before and after ACQ type C (0.5% Cu elemental) treatment for a retention of 3.2 kg/m^3 and post treatments

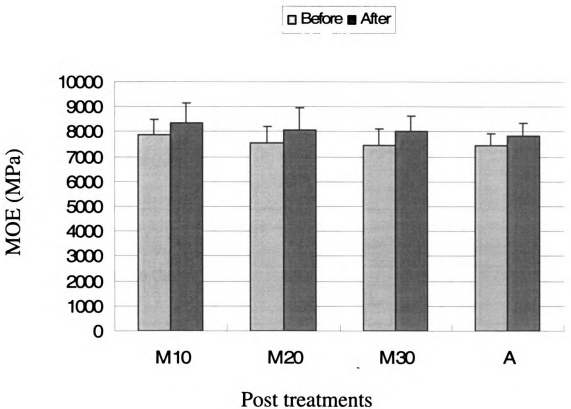

Figure 4.6 Non Destructive MOE of southern yellow pine before and after ACQ type C (0.8% Cu elemental) treatment for a retention of 4.9 kg/m^3 and post treatments

Table 4.8 Destructive MOE after ACQ type C and post treatments

Treating solution concentration	Cu retention (kg/m3)	Post treatment	MOE (M Pa)	
			Average	Stdev
0.5% Cu	3.2	M10	10191	978
		M20	10302	888
		M30	10398	858
		A	10100	835
		Control	10040	923
0.8% Cu	4.9	M10	10786	1070
		M20	10712	1055
		M30	10152	935
		A	10150	986
		Control	10040	923

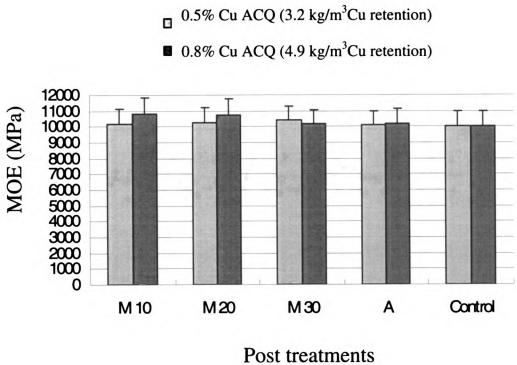

Figure 4.7 Destructive MOE after ACQ type C and post treatments

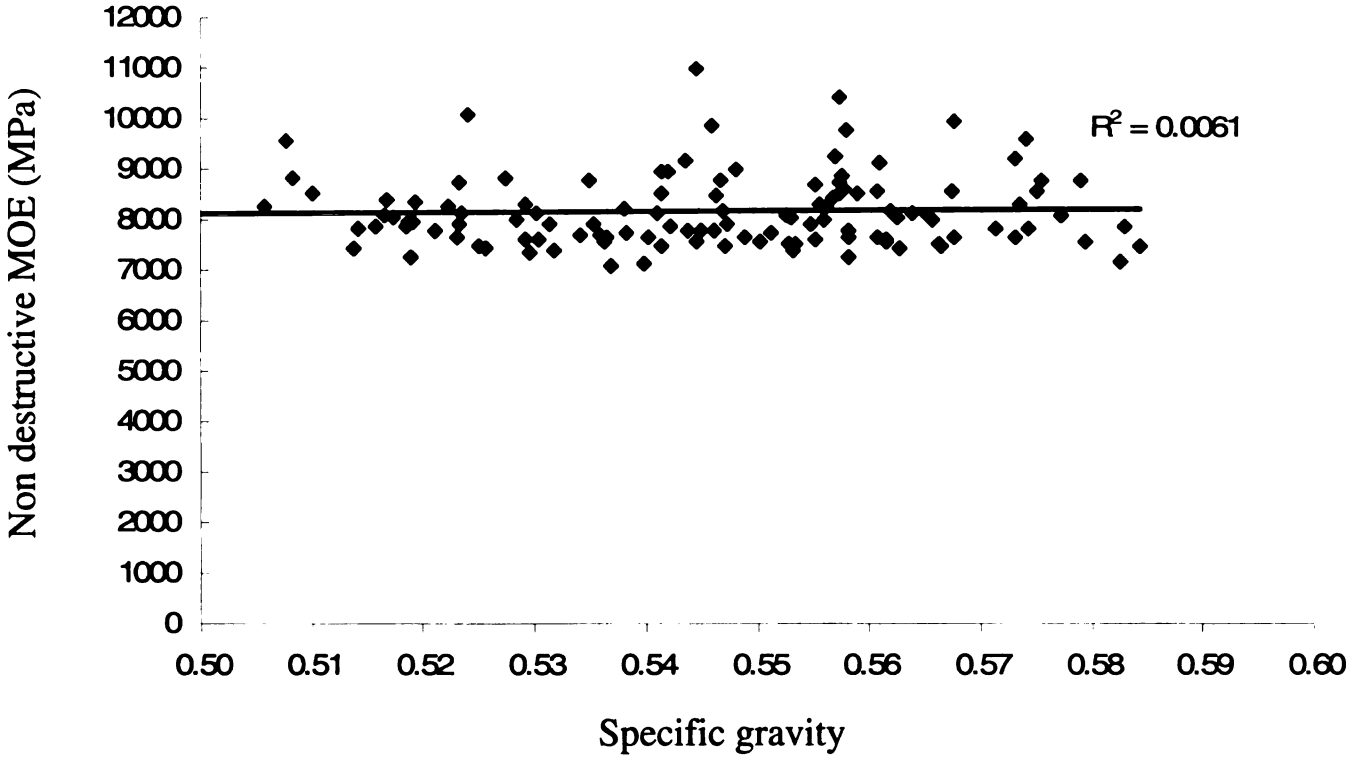

Figure 4.8 Non- Destructive MOE after post treatment and specific gravity relation.

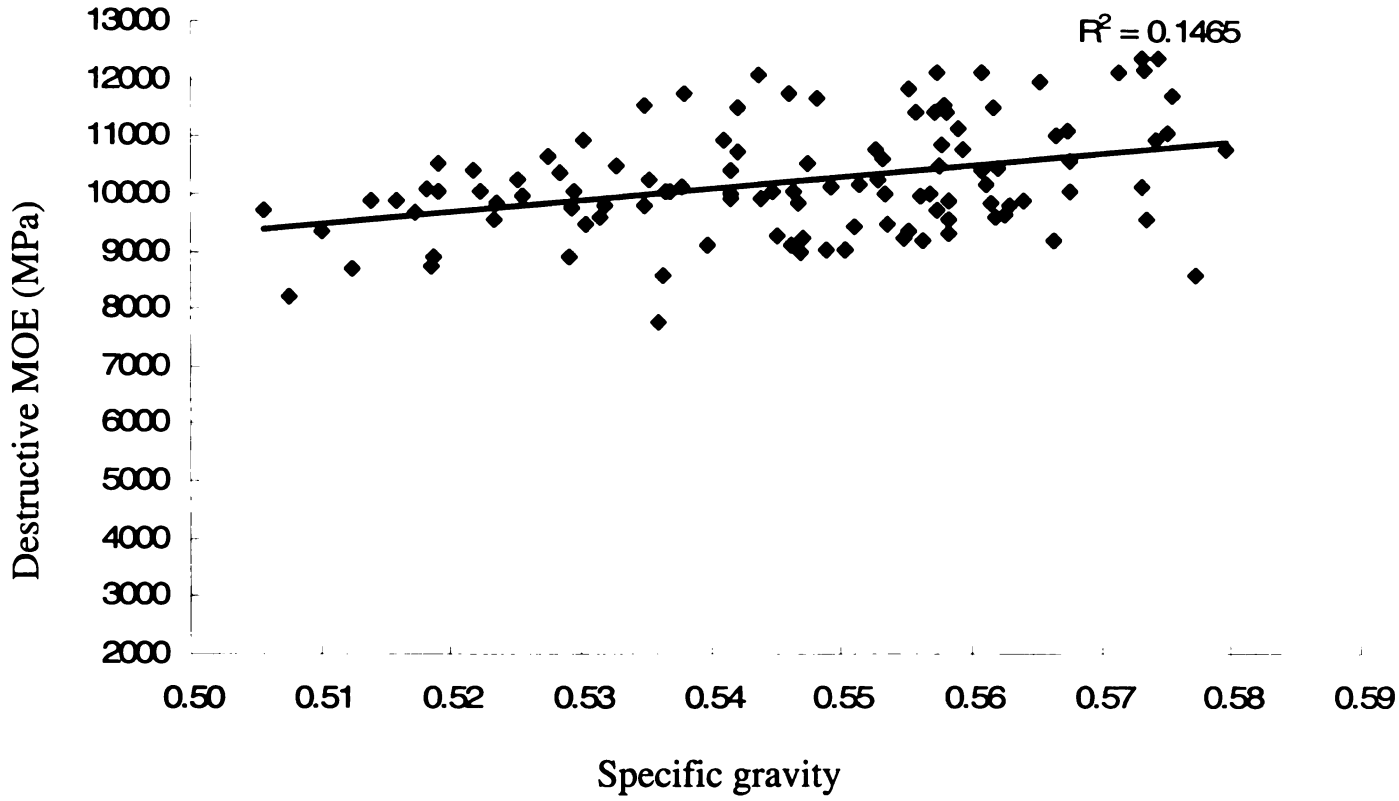

Figure 4.9 Destructive MOE and specific gravity relation

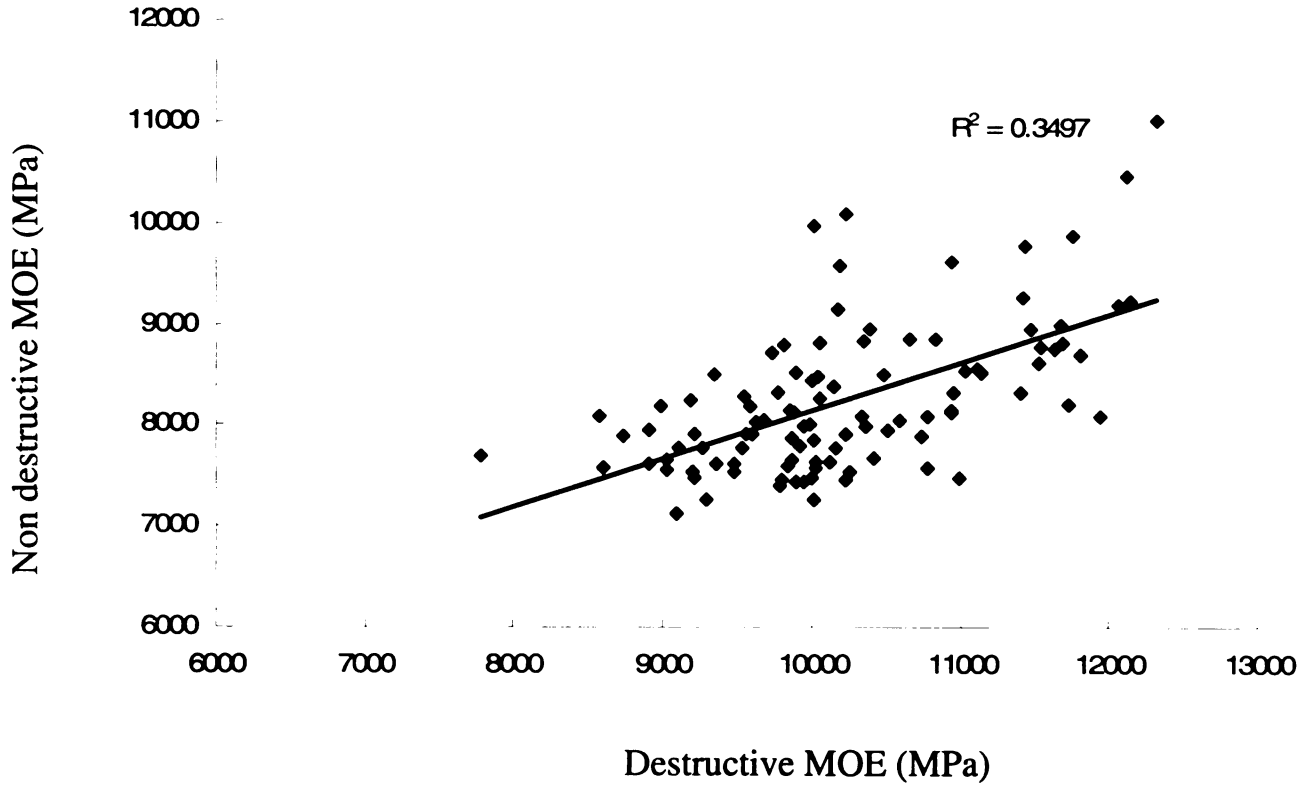

Figure 4.10 Relation of destructive and non- destructive MOE after post treatment

Table 4.9 MOR of ACQ type C and post treated southern yellow pine

Treating solution concentration	Cu retention (kg/m^3)	Post treatment	MOR (M Pa)	
			Average	Stdev
0.5% Cu	3.2	M10	103	8
		M20	103	9
		M30	103	5
		A	104	10
		Control	102	9
R2 = 0.8% Cu	4.9	M10	110	7
		M20	110	10
		M30	109	8
		A	109	5
		Control	102	9

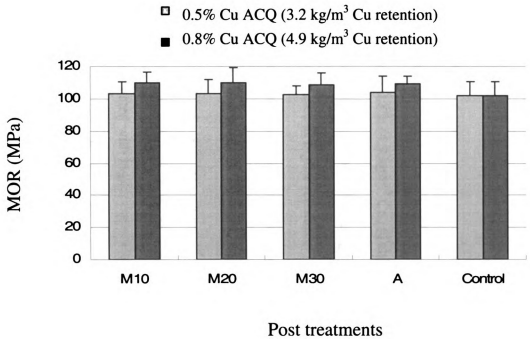

Figure 4.11 MOR after ACQ type C and post treatments

4.5 Color change - ΔE

Color change of southern yellow pine samples from green condition after ACQ type C and post treatment were detailed in appendix table 15 and summarized in table 4.10 and figure 4.12. Light yellow color of southern yellow pine was changed to light bluish green after ACQ and post treatment.

Lightness 'L' value of southern yellow pine observed to decrease after ACQ type D and post treatments. Average percentage decrease in 'L'was -31% to -32% for samples treated with 0.5% copper elemental ACQ (3.2 kg/m^3 Cu) compared to -37% to -39% for samples treated with 0.8% (4.9 kg/m^3 Cu) (Table 4.10). This result shows that lightness of southern yellow pine decreasing after ACQ type C. The decrease in lightness was higher for samples treated at higher retention.

Chromaticity 'a' of the same samples also observed to decrease after ACQ type C and post treatment. An average decrease of -79% to -84% was observed for samples treated at 3.2 kg/m^3 copper retention compared to -99 to -111% for samples treated at 4.9 kg/m^3, showing that chromaticity 'a' value is shifting from red to green, and the shift is higher for samples treated with higher copper retention (Table 4.10). Same trend was observed with chromaticity 'b'. An average decrease of -32 to -41% was observed for samples treated at 3.2 kg/m^3 copper retention compared to -36 to -38% for samples treated at 4.9 kg/m^3, showing the shift towards blue from yellow (Table 4.10). Statistical analysis of the color change data shows that concentration of treating solution has a significant effect on color change of the sample from green condition after ACQ and post treatment ($Pr<0.001$).

Southern yellow pine treated at 3.2 kg/m^3 copper retention showed a color change, ΔE value of 27.94 and 27.69 for air dried and 30 minute microwave post treated samples. At the same time samples treated at 4.9 kg/m^3 showed a color change of 32.31 and 34.49 respectively for air dried and 30 minute microwave post treated samples (Table 4.10). No significant difference in color change was observed among air dried and microwave post treated sample within retention level (Pr>0.5559). These results shows that 30 minute microwave post treated samples retain the same color as air dried samples. Heating wood at high temperature will result in the formation of colored substances from oxidation of the phenolic compound of the wood and the formation of dark material from the hydrolysis of hemicellulose and lignin (Hon and Minemura, 2000) to cause a discoloration. This implies that increase in temperature up to 64-70^{0}C during microwave post treatment not resulting in the formation of colored substances in the wood to have a discoloration.

Table. 4.10 Lightness 'L'and chromaticity co-ordinates 'a' and 'b' of samples after ACQ type C and post treatment

Treatment	Lightness L				Chromaticity a				Chromaticity b				Color change ΔE
	Initial L L_i	Final L L_f	ΔL (L_f-L_i)	Change % $\Delta L/L_i$ (%)	Initial a a_i	Final a a_f	Δa (a_f-a_i)	Change % $\Delta a/a_i$ (%)	Initial b b_i	Final b b_f	Δb (b_f-b_i)	Change % $\Delta b/b_i$ (%)	
R1M10	82.75	56.31	-26.44	-32	5.23	0.88	-4.36	-84	26.18	16.44	-9.74	-37	28.56
R1M20	81.53	56.00	-25.53	-31	5.43	1.18	-4.25	-79	25.72	17.59	-8.12	-32	27.14
R1M30	79.70	55.17	-24.53	-31	6.52	1.36	-5.15	-79	28.28	16.62	-11.66	-41	27.69
R1A	81.81	55.83	-25.98	-32	5.52	0.89	-4.63	-84	26.50	17.35	-9.15	-35	27.94
R2M10	82.78	52.43	-30.34	-37	4.97	-0.54	-5.50	-111	26.23	16.23	-10.00	-38	32.43
R2M20	82.00	51.77	-30.23	-37	5.22	0.11	-5.12	-99	26.27	16.42	-9.86	-37	32.25
R2M30	83.69	50.73	-32.95	-39	4.33	0.02	-4.31	-100	25.03	15.85	-9.18	-36	34.49
R2A	82.47	52.35	-30.13	-37	5.33	-0.38	-5.72	-108	27.10	17.06	-10.04	-36	32.31

Where R1 represents sample treated with ACQ having 0.5% Cu for a copper retention of 3.2 kg/m^3, R2 represents sample treated with ACQ having 0.8% Cu for a copper retention of 4.9 kg/m^3

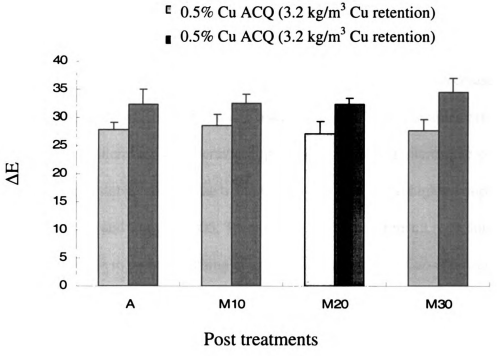

Figure 4.12 Color change, ΔE after ACQ type C and post treatments

CONCLUSIONS

Percentage of copper leached from thirty minute microwave post treated samples, treated with ACQ type C at a copper retention of 3.2 kg/m^3 was 13% while 17% copper leaching was observed for air dry post treated samples. At the same time percentage of copper leached from thirty minutes microwave post treated samples, treated at a copper retention of 4.9 kg/ m^3 was 19% compared to 22% observed for air dry post treated samples. These results concludes that microwave post treatment can be used to reduce the leaching of copper from ACQ type C treated southern yellow pine. Decrease in copper leaching observed for thirty minute microwave post treated samples can be attributed to rapid increase in temperature (up to 64-70^{0}C) during microwave post treatment. Copper stabilization in the treated wood will increase at higher temperature (Pasek, 2003; Ung and Cooper, 2005; Tascioglu, 2005). Similar result regarding the effect of microwave to reduce leaching of copper was reported by Cao and Kamdem (2004) in copper amine treated southern yellow pine. They reported 15% copper leaching for air dried samples treated with copper amine for a copper retention of 3.2 kg/m^3 compared to 8.4% for twenty minute microwave post treated samples.

Increase in microwave duration from zero minutes to thirty minute reduced copper leaching from 33% to 13% in case of samples treated with ACQ for a copper retention of 3.2 kg/m^3 compared to 42% to 19% in case of samples treated at copper retention of 4.9 kg/m^3. Same trend of decreasing copper leaching with increasing microwave duration was observed by Cao and Kamdem (2004).

Percentage of copper leached from air dry post treated sample treated at a copper retention of 3.2 kg/m^3 and 4.9 kg/m^3 was 17% and 22% respectively. Percentage of copper leached from thirty minute microwave post treated sample treated at a copper retention of 3.2 kg/m^3 and 4.9 kg/m^3 was 13% and 19% respectively. These results conclude that copper leaching will be higher for samples treated at higher copper retention invariably of the post treatments. Similar results have been reported by Pasek (2003), Tascioglu et al (2005), and Ung and Cooper (2005). Increase in copper leaching with increase in copper retention can be explained by the fact that in case of samples treated at higher retention more copper complex is competing to undergo cation exchange reaction with wood components. As the number of anionic sites is limited in wood, the amount of unreacted preservative components in the treated wood will be higher for samples at higher retention, which will result in higher copper loss.

Average destructive MOE of the control sample was 10040 MPa. MOE of air dry and 30 minute microwave post treated samples, treated at 3.2 kg/m3 was 10100 MPa and 10398 MPa respectively compared to 10150 MPa and 10152 MPa for samples treated at 4.9 kg/m^3. MOE of the air dry and microwave post treated samples are not significantly different from the control samples. It can be concluded from the results that ACQ treatment not resulting in the reduction of MOE of southern yellow pine in agreement with Barnes et al (1993). No published research is available in the literature regarding the effect of microwave post treatment on strength properties of treated wood. Present study shows that increase in temperature up to 64-70^{0}C after thirty minute microwave not resulting in degradation of wood components to cause any reduction in MOE.

Average MOR of control sample was 102 MPa. MOR of air dry and 30 minute microwave post treated samples, treated at 3.2 kg/m^{3}was 104 MPa and 103 MPa respectively compared to 109 MPa and 109 MPa for samples treated at 4.9 kg/m^3. There was no significant difference in MOR of air dry and microwave post treated samples compared to the control samples. This implies that ACQ treatment not reducing the MOR of southern yellow pine in agreement with Barnes et al (1993). It can be concluded from the result that thirty minute microwave not resulting in degradation of wood components to cause reduction in MOR.

Color change, ΔE of air dry and microwave post treated southern yellow pine treated at 3.2 kg/m^3 copper retention was 27.94 and 27.69 respectively compared to 32.31 and 34.49 for samples treated at 4.9 kg/m^3. Color changes of thirty 30 minute microwave post treated samples are not significantly different from air dry post treated samples irrespective of the retention. It is reported that at higher temperature colored substances may formed in wood by the oxidation of phenolic compounds of the wood and hydrolysis of hemicellulose and lignin (Hon and Minemura, 2000). Results suggest that increase in temperature during 30 minute microwave not resulting in the formation of colored substances in the wood.

In conclusion microwave post treatment is effective to reduce migration of copper from ACQ type C treated southern yellow pine without reduction in bending strength and no significant color change compared to air dry post treated samples.

APPENDIX

Table 1. Copper content in southern yellow pine treated with ACQ type C having 0.5% copper

Where W1 is weight before treatment, W2 is weight after treatment

Treatment	Sample	W1 (g)	W2 (g)	W2-W1 (g)	Copper content (mg) (W2-W1) * 0.5% * 1000
M0-1	1	4.5	9.31	4.81	24.05
	2	3.81	8.94	5.13	25.65
	3	4.27	7.87	3.6	18.00
	4	3.95	8.23	4.28	21.40
	5	4.24	8.99	4.75	23.75
	6	3.78	8.7	4.92	24.60
Copper content in 6 blocks - 137.58					
M0-2	7	4.14	8.51	4.37	21.85
	8	4.46	9.11	4.65	23.25
	9	4.24	8.87	4.63	23.15
	10	4.08	8.84	4.76	23.80
	11	3.84	7.45	3.61	18.05
	12	4.51	7.82	3.31	16.55
Copper content in 6 blocks - 126.65					
M10-1	13	4.04	9.08	5.04	25.20
	14	4.56	9.31	4.75	23.75
	15	4.22	9.11	4.89	24.45
	16	4.52	9.11	4.59	22.95
	17	4.02	8.76	4.74	23.70
	18	4.42	7.95	3.53	17.65
Copper content in 6 blocks - 137.70					
M10-2	19	3.75	8.03	4.28	21.40
	20	4.59	8.63	4.04	20.20
	21	4.35	9.01	4.66	23.30
	22	4.19	8.26	4.07	20.35
	23	4.47	8.14	3.67	18.35
	24	4.46	9.04	4.58	22.90
Copper content in 6 blocks - 126.50					
M20-1	25	3.78	8.01	4.23	21.15
	26	4.58	9.02	4.44	22.20
	27	4.56	9.1	4.54	22.70
	28	4.5	9.08	4.58	22.90
	29	4.42	8.91	4.49	22.45
	30	4.49	8.99	4.5	22.50
Copper content in 6 blocks - 133.90					

Table 1 continued

M20-2	31	4.53	9.21	4.68	23.40
	32	4.66	9.41	4.75	23.75
	33	4.44	9.26	4.82	24.10
	34	4.27	9.17	4.9	24.50
	35	4.35	8.95	4.6	23.00
	36	4.64	9.45	4.81	24.05
Copper content in 6 blocks - 142.80					
M30-1	37	4.47	9.07	4.6	23.00
	38	4.6	9.22	4.62	23.10
	39	4.49	9.08	4.59	22.95
	40	3.95	8.48	4.53	22.65
	41	4.37	9.06	4.69	23.45
	42	4.51	9.11	4.6	23.00
Copper content in 6 blocks - 138.15					
M30-2	43	4.41	9.09	4.68	23.40
	44	4.46	9.09	4.63	23.15
	45	4.58	8.74	4.16	20.80
	46	4.48	8.92	4.44	22.20
	47	4.31	8.87	4.56	22.80
	48	4.44	8.68	4.24	21.20
Copper content in 6 blocks - 133.55					
A-1	61	4.55	8.88	4.33	21.65
	62	4.03	8.67	4.64	23.20
	63	4.63	8.86	4.23	21.15
	64	4.45	9.02	4.57	22.85
	65	4.54	9.19	4.65	23.25
	66	4.48	8.98	4.5	22.50
Copper content in 6 blocks - 134.60					
A-2	67	4.58	9.08	4.5	22.50
	68	4.58	9.69	5.11	25.55
	69	4.41	7.79	3.38	16.90
	70	4.43	8.46	4.03	20.15
	71	4.54	9.14	4.6	23.00
	72	4.36	9.00	4.64	23.20
Copper content in 6 blocks - 131.30					

Table 2. Copper content in southern yellow pine treated with ACQ type C having 0.8% copper

Treatment	Sample	W1 (g)	W2 (g)	W2-W1 (g)	Copper content (mg) (W2-W1) * 0.8% *1000
M0-1	173	4.85	8.73	3.88	31.04
	174	4.39	8.96	4.57	36.56
	175	4.43	8.58	4.15	33.20
	176	4.54	8.09	3.55	28.40
	177	4.13	8.60	4.47	35.76
	178	4.70	9.17	4.47	35.76
Copper content in 6 blocks - 200.72					
M0-2	179	4.48	8.55	4.07	32.56
	180	4.32	8.76	4.44	35.52
	181	4.36	9.39	5.03	40.24
	182	4.42	7.96	3.54	28.32
	183	4.00	8.99	4.99	39.92
	184	4.86	8.56	3.70	29.60
Copper content in 6 blocks - 206.16					
M10-1	188	4.76	9.21	4.45	35.60
	189	4.81	8.93	4.12	32.96
	190	4.21	9.15	4.94	39.52
	191	4.84	8.80	3.96	31.68
	192	4.10	8.76	4.66	37.28
	193	4.70	8.95	4.25	34.00
Copper content in 6 blocks - 211.04					
M10-2	194	4.17	9.04	4.87	38.96
	195	4.88	9.08	4.20	33.60
	196	4.61	9.06	4.45	35.60
	197	4.67	8.76	4.09	32.72
	198	4.55	9.14	4.59	36.72
	199	4.61	9.01	4.40	35.20
Copper content in 6 blocks - 212.8					
M20-1	200	4.88	9.00	4.12	32.96
	201	4.57	8.32	3.75	30.00
	202	4.54	9.02	4.48	35.84
	203	4.24	8.94	4.70	37.60
	204	4.47	9.09	4.62	36.96
	205	4.16	9.01	4.85	38.80
Copper content in 6 blocks - 212.16					
M20-2	206	4.12	8.87	4.75	38.00
	207	4.11	8.65	4.54	36.32
	208	4.83	9.20	4.37	34.96
	209	4.18	9.08	4.90	39.20
	210	4.52	8.77	4.25	34.00
	211	4.33	8.46	4.13	33.04
Copper content in 6 blocks - 215.52					

Table 2 continued

M30-1	215	4.90	9.46	4.56	36.48
	216	4.69	9.04	4.35	34.80
	217	4.16	9.32	5.16	41.28
	218	4.89	9.03	4.14	33.12
	219	4.28	9.11	4.83	38.64
	220	4.53	8.84	4.31	34.48
Copper content in 6 blocks - 218.8					
M30-2	401	4.48	9.21	4.73	37.84
	402	4.45	9.34	4.89	39.12
	403	4.13	8.37	4.24	33.92
	404	4.31	8.49	4.18	33.44
	405	4.79	9.32	4.53	36.24
	406	4.86	9.46	4.60	36.80
Copper content in 6 blocks - 217.36					
A-1	410	4.41	8.51	4.10	32.80
	411	4.45	9.11	4.66	37.28
	412	4.91	9.12	4.21	33.68
	413	4.42	8.68	4.26	34.08
	414	4.91	8.24	3.33	26.64
	415	4.86	8.89	4.03	32.24
Copper content in 6 blocks - 196.72					
A-2	416	4.91	9.32	4.41	35.28
	417	4.15	8.58	4.43	35.44
	418	4.62	9.16	4.54	36.32
	419	4.92	8.54	3.62	28.96
	420	4.93	8.54	3.61	28.88
	421	4.24	8.02	3.78	30.24
Copper content in 6 blocks - 195.12					

Table 3. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.5% copper, for a copper retention of 3.2 kg/m^3 with no post treatment

Where 'AA' is atomic absorption reading of leachate for copper,'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	M0				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	12.80	10	38.40	38.40	28
	2	12.22	10	36.65	36.65	29
Average		**12.51**	10	**37.52**	**37.52**	**28**
24	1	14.49	1	4.35	42.75	31
	2	13.59	1	4.08	40.72	32
Average		**14.04**	1	**4.21**	**41.74**	**32**
48	1	4.03	1	1.21	43.96	32
	2	3.63	1	1.09	41.81	33
Average		**3.83**	1	**1.15**	**42.88**	**32**
96	1	0.68	1	0.20	44.16	32
	2	1.27	1	0.38	42.19	33
Average		**0.97**	1	**0.29**	**43.18**	**33**
144	1	0.67	1	0.20	44.36	32
	2	0.71	1	0.21	42.40	33
Average		**0.69**	1	**0.21**	**43.38**	**33**
192	1	0.48	1	0.14	44.51	32
	2	0.31	1	0.09	42.49	34
Average		**0.40**	1	**0.12**	**43.50**	**33**
240	1	0.26	1	0.08	44.58	32
	2	0.22	1	0.06	42.56	34
Average		**0.24**	1	**0.07**	**43.57**	**33**
288	1	0.38	1	0.12	44.70	33
	2	0.30	1	0.09	42.65	34
Average		**0.34**	1	**0.10**	**43.67**	**33**
336	1	0.27	1	0.08	44.78	33
	2	0.20	1	0.06	42.71	34
Average		**0.24**	1	**0.07**	**43.74**	**33**

Table 4. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.5% copper, for a copper retention of 3.2 kg/m^3 and post treated for 10 minutes microwave

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	M10				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	7.89	10	23.67	23.67	17
	2	7.13	10	21.39	21.39	17
Average		**7.51**	10	**22.53**	**22.53**	**17**
24	1	2.41	10	7.23	30.90	22
	2	2.89	10	8.67	30.06	24
Average		**2.65**	1	**7.95**	**30.48**	**23**
48	1	11.87	1	3.56	34.46	25
	2	8.60	1	2.58	32.64	26
Average		**10.24**	1	**3.07**	**33.55**	**25**
96	1	2.07	1	0.62	35.08	25
	2	2.21	1	0.66	33.30	26
Average		**2.14**	1	**0.64**	**34.19**	**26**
144	1	2.26	1	0.68	35.76	26
	2	1.59	1	0.48	33.78	27
Average		**1.92**	1	**0.58**	**34.77**	**26**
192	1	0.86	1	0.26	36.02	26
	2	0.57	1	0.17	33.95	27
Average		**0.72**	1	**0.21**	**34.99**	**26**
240	1	0.39	1	0.12	36.13	26
	2	0.34	1	0.10	34.05	27
Average		**0.36**	1	**0.11**	**35.09**	**27**
288	1	0.46	1	0.14	36.27	26
	2	0.68	1	0.20	34.26	27
Average		**0.57**	1	**0.17**	**35.26**	**27**
336	1	0.43	1	0.13	36.40	26
	2	0.63	1	0.19	34.45	27
Average		**0.53**	1	**0.16**	**35.42**	**27**

Table 5. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.5% copper, for a copper retention of 3.2 kg/m^3 and post treated for 20 minutes microwave

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	M20				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	3.76	10	11.28	11.28	8
	2	4.06	10	12.18	12.18	9
Average		**3.91**	10	**11.73**	**11.73**	**8**
24	1	2.58	10	7.73	19.01	14
	2	2.56	10	7.67	19.85	14
Average		**2.57**	1	**7.70**	**19.43**	**14**
48	1	6.22	1	1.87	20.87	16
	2	5.36	1	1.61	21.46	15
Average		**5.79**	1	**1.74**	**21.16**	**15**
96	1	3.27	1	0.98	21.85	16
	2	2.07	1	0.62	22.08	15
Average		**2.67**	1	**0.80**	**21.96**	**16**
144	1	3.10	1	0.93	22.78	17
	2	2.42	1	0.72	22.80	16
Average		**2.76**	1	**0.83**	**22.79**	**16**
192	1	0.58	1	0.17	22.96	17
	2	0.56	1	0.17	22.97	16
Average		**0.57**	1	**0.17**	**22.96**	**17**
240	1	0.73	1	0.22	23.17	17
	2	0.66	1	0.20	23.16	16
Average		**0.69**	1	**0.21**	**23.17**	**17**
288	1	0.62	1	0.19	23.36	17
	2	0.59	1	0.18	23.34	16
Average		**0.60**	1	**0.18**	**23.35**	**17**
336	1	0.84	1	0.25	23.61	18
	2	0.89	1	0.27	23.61	17
Average		**0.86**	1	**0.26**	**23.61**	**17**

Table 6. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.5% copper, for a copper retention of 3.2 kg/m^3 and post treated for 30 minutes microwave

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	M30				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	2.60	10	7.81	7.81	6
	2	2.80	10	8.41	8.41	6
Average		**2.70**	10	**8.11**	**8.11**	**6**
24	1	17.10	1	5.13	12.93	9
	2	17.22	1	5.16	13.57	10
Average		**17.16**	1	**5.15**	**13.25**	**10**
48	1	3.35	1	1.01	13.94	10
	2	3.32	1	1.00	14.57	11
Average		**3.34**	1	**1.00**	**14.25**	**10**
96	1	4.42	1	1.32	15.26	11
	2	4.44	1	1.33	15.90	12
Average		**4.43**	1	**1.33**	**15.58**	**11**
144	1	4.16	1	1.25	16.51	12
	2	3.53	1	1.06	16.96	13
Average		**3.84**	1	**1.15**	**16.73**	**12**
192	1	0.83	1	0.25	16.76	12
	2	0.50	1	0.15	17.11	13
Average		**0.66**	1	**0.20**	**16.93**	**12**
240	1	0.43	1	0.13	16.89	12
	2	0.42	1	0.13	17.23	13
Average		**0.43**	1	**0.13**	**17.06**	**13**
288	1	0.73	1	0.22	17.11	12
	2	0.52	1	0.16	17.39	13
Average		**0.63**	1	**0.19**	**17.25**	**13**
336	1	0.62	1	0.19	17.30	13
	2	0.81	1	0.24	17.63	13
Average		**0.71**	1	**0.21**	**17.46**	**13**

Table 7. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.5% copper, for a copper retention of 3.2 kg/m^3 and post treated for 21 days air drying

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	A				
		AA (mg/l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	3.91	10	11.73	11.73	9
	2	4.00	10	11.99	11.99	9
Average		**3.95**	10	**11.86**	**11.86**	**9**
24	1	16.69	1	5.01	16.74	12
	2	15.04	1	4.51	16.50	13
Average		**15.87**	1	**4.76**	**16.62**	**12**
48	1	8.20	1	2.46	19.20	14
	2	8.82	1	2.65	19.14	15
Average		**8.51**	1	**2.55**	**19.17**	**14**
96	1	5.15	1	1.54	20.74	15
	2	4.70	1	1.41	20.55	16
Average		**4.92**	1	**1.48**	**20.65**	**16**
144	1	1.81	1	0.54	21.28	16
	2	1.92	1	0.58	21.13	16
Average		**1.86**	1	**0.56**	**21.21**	**16**
192	1	1.82	1	0.55	21.83	16
	2	1.77	1	0.53	21.66	16
Average		**1.79**	1	**0.54**	**21.74**	**16**
240	1	0.34	1	0.10	21.93	16
	2	0.55	1	0.16	21.82	17
Average		**0.44**	1	**0.13**	**21.88**	**16**
288	1	0.54	1	0.16	22.09	16
	2	0.74	1	0.22	22.04	17
Average		**0.64**	1	**0.19**	**22.07**	**17**
336	1	0.32	1	0.10	22.19	16
	2	0.42	1	0.13	22.17	17
Average		**0.37**	1	**0.11**	**22.18**	**17**

Table 8. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.8% copper, for a copper retention of 4.9 kg/m^3 with no post treatment

Where 'AA' is atomic absorption reading of leachate for copper,'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	M0				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	17.88	10	53.64	53.64	27
	2	16.52	10	49.56	49.56	24
Average		**17.20**	**10**	**51.60**	**51.60**	**25**
24	1	7.09	10	21.26	74.90	37
	2	8.15	10	24.46	74.02	36
Average		**7.62**	**10**	**22.86**	**74.46**	**37**
48	1	1.83	10	5.50	80.40	40
	2	2.31	10	6.94	80.96	39
Average		**2.07**	**10**	**6.22**	**80.68**	**40**
96	1	9.19	1	2.76	83.16	41
	2	10.01	1	3.00	83.96	41
Average		**9.60**	**1**	**2.88**	**83.56**	**41**
144	1	2.35	1	0.71	83.87	42
	2	2.62	1	0.79	84.75	41
Average		**2.49**	**1**	**0.75**	**84.31**	**41**
192	1	1.06	1	0.32	84.18	42
	2	1.16	1	0.35	85.10	41
Average		**1.11**	**1**	**0.33**	**84.64**	**42**
240	1	0.76	1	0.23	84.41	42
	2	0.92	1	0.28	85.37	41
Average		**0.84**	**1**	**0.25**	**84.89**	**42**
288	1	0.64	1	0.19	84.60	42
	2	0.70	1	0.21	85.58	42
Average		**0.67**	**1**	**0.20**	**85.09**	**42**
336	1	0.53	1	0.16	84.76	42
	2	0.62	1	0.19	85.77	42
Average		**0.57**	**1**	**0.17**	**85.26**	**42**

Table 9. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.8% copper, a copper retention of 4.9 kg/m^{3}and post treated for 10 minutes microwave

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	M10				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	14.85	10	44.54	44.54	21
	2	13.33	10	40.00	40.00	19
Average		**14.09**	**10**	**42.27**	**42.27**	**20**
24	1	5.07	10	15.21	59.75	28
	2	5.15	10	15.46	55.46	26
Average		**5.11**	**10**	**15.34**	**57.60**	**27**
48	1	19.66	1	5.90	65.65	31
	2	21.21	1	6.36	61.82	29
Average		**20.43**	**1**	**6.13**	**63.73**	**30**
96	1	8.40	1	2.52	68.17	32
	2	10.70	1	3.21	65.03	31
Average		**9.55**	**1**	**2.86**	**66.60**	**31**
144	1	2.58	1	0.77	68.94	33
	2	3.04	1	0.91	65.94	31
Average		**2.81**	**1**	**0.84**	**67.44**	**32**
192	1	0.97	1	0.29	69.23	33
	2	1.26	1	0.38	66.32	31
Average		**1.11**	**1**	**0.33**	**67.78**	**32**
240	1	0.76	1	0.23	69.46	33
	2	0.73	1	0.22	66.54	31
Average		**0.74**	**1**	**0.22**	**68.00**	**32**
288	1	0.71	1	0.21	69.67	33
	2	0.69	1	0.21	66.74	31
Average		**0.70**	**1**	**0.21**	**68.21**	**32**
336	1	0.62	1	0.19	69.86	33
	2	0.55	1	0.17	66.91	31
Average		**0.59**	**1**	**0.18**	**68.38**	**32**

Table 10. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.8% copper, a copper retention of 4.9 kg/m^{3}and post treated for 20 minutes microwave

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached

Duration (hr)	Rep	M20				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	13.80	10	41.41	41.41	20
	2	13.90	10	41.71	41.71	19
Average		**13.85**	**10**	**41.56**	**41.56**	**19**
24	1	3.86	10	11.58	52.99	25
	2	4.17	10	12.50	54.20	25
Average		**4.01**	**10**	**12.04**	**53.59**	**25**
48	1	19.43	1	5.83	58.82	28
	2	20.49	1	6.15	60.35	28
Average		**19.96**	**1**	**5.99**	**59.58**	**28**
96	1	10.75	1	3.23	62.04	29
	2	11.20	1	3.36	63.71	30
Average		**10.98**	**1**	**3.29**	**62.87**	**29**
144	1	3.39	1	1.02	63.06	30
	2	3.70	1	1.11	64.82	30
Average		**3.55**	**1**	**1.06**	**63.94**	**30**
192	1	1.48	1	0.44	63.50	30
	2	1.31	1	0.39	65.21	30
Average		**1.39**	**1**	**0.42**	**64.36**	**30**
240	1	0.96	1	0.29	63.79	30
	2	0.98	1	0.29	65.51	30
Average		**0.97**	**1**	**0.29**	**64.65**	**30**
288	1	0.75	1	0.23	64.01	30
	2	0.78	1	0.23	65.74	31
Average		**0.77**	**1**	**0.23**	**64.88**	**30**
336	1	0.63	1	0.19	64.20	30
	2	0.65	1	0.20	65.94	31
Average		**0.64**	**1**	**0.19**	**65.07**	**30**

Table 11. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.8% copper, a copper retention of 4.9 kg/m^{3}and post treated for 30 minutes microwave

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached

Duration (hr)	Rep	M30				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	7.38	10	22.13	22.13	10
	2	7.73	10	23.20	23.20	11
Average		**7.56**	**10**	**22.67**	**22.67**	**10**
24	1	2.94	10	8.81	30.94	14
	2	3.58	10	10.73	33.93	16
Average		**3.26**	**10**	**9.77**	**32.43**	**15**
48	1	14.70	1	4.41	35.35	16
	2	17.42	1	5.23	39.15	18
Average		**16.06**	**1**	**4.82**	**37.25**	**17**
96	1	9.19	1	2.76	38.11	17
	2	10.00	1	3.00	42.15	19
Average		**9.59**	**1**	**2.88**	**40.13**	**18**
144	1	3.31	1	0.99	39.10	18
	2	3.76	1	1.13	43.28	20
Average		**3.54**	**1**	**1.06**	**41.19**	**19**
192	1	1.74	1	0.52	39.62	18
	2	1.70	1	0.51	43.79	20
Average		**1.72**	**1**	**0.52**	**41.71**	**19**
240	1	1.11	1	0.33	39.95	18
	2	1.11	1	0.33	44.12	20
Average		**1.11**	**1**	**0.33**	**42.04**	**19**
288	1	0.88	1	0.26	40.22	18
	2	0.83	1	0.25	44.37	20
Average		**0.86**	**1**	**0.26**	**42.30**	**19**
336	1	0.66	1	0.20	40.42	18
	2	0.61	1	0.18	44.56	20
Average		**0.63**	**1**	**0.19**	**42.49**	**19**

Table 12. Cumulative and percentage copper leached from southern yellow pine treated with ACQ type C, having 0.8% copper, a copper retention of 4.9 kg/m^{3}and post treated for 21 days air drying (A)

Where 'AA' is atomic absorption reading of leachate for copper, 'Rep' is replication, 'Cu 300 ml' is copper leached in 300 ml water in mg, 'C Cu' is cumulative copper leached in mg, '% Cu' is percentage copper leached.

Duration (hr)	Rep	A				
		AA (mg /l)	DF	Cu 300 ml (mg)	C Cu (mg)	% Cu
6	1	7.21	10	21.63	21.63	11
	2	7.42	10	22.26	22.26	11
Average		**7.32**	**10**	**21.95**	**21.95**	**11**
24	1	3.90	10	11.70	33.33	17
	2	3.73	10	11.19	33.45	17
Average		**3.81**	**10**	**11.44**	**33.39**	**17**
48	1	12.44	1	3.73	37.06	19
	2	12.49	1	3.75	37.19	19
Average		**12.47**	**1**	**3.74**	**37.13**	**19**
96	1	9.48	1	2.84	39.91	20
	2	9.54	1	2.86	40.05	21
Average		**9.51**	**1**	**2.85**	**39.98**	**20**
144	1	4.65	1	1.39	41.30	21
	2	4.69	1	1.41	41.46	21
Average		**4.67**	**1**	**1.40**	**41.38**	**21**
192	1	2.77	1	0.83	42.13	21
	2	2.46	1	0.74	42.20	22
Average		**2.61**	**1**	**0.78**	**42.17**	**22**
240	1	2.12	1	0.64	42.77	22
	2	2.13	1	0.64	42.84	22
Average		**2.12**	**1**	**0.64**	**42.80**	**22**
288	1	2.11	1	0.63	43.40	22
	2	2.18	1	0.65	43.49	22
Average		**2.15**	**1**	**0.64**	**43.45**	**22**
336	1	1.77	1	0.53	43.93	22
	2	1.51	1	0.45	43.94	23
Average		**1.64**	**1**	**0.49**	**43.94**	**22**

Table 13. Non- destructive MOE before and after ACQ type C and post treatments

Where 't' is thickness, 'w' width, 'l' length, 'SG' is specific gravity (dry weight/volume), 'Li' is load required to make a displacement of 0.19 cm before ACQ type C and post treatments, 'Lf' is load required to make a displacement of 0.19 cm after ACQ type C and post treatments, 'MOEi' is MOE before ACQ type C and post treatments, 'MOEf' is MOE after ACQ type C and post treatments, R1 represents samples treated with 0.5% Cu ACQ for a copper retention of 3.2 kg/m^3. R2 represents samples treated with 0.8% ACQ for a copper retention of 4.9 kg/m^3.

Treatment	Sample	t (cm)	w (cm)	l (cm)	V (cm3)	Dry weight (g)	SG	Li (Kg)	MOE i (M Pa)	Lf (Kg)	MOE f (Mpa)	Change in MOE (%)
R1M10	1	1.29	1.23	22.86	36.27	20.13	0.55	27.09	7529.89	28.42	7900.71	4.92
	2	1.27	1.23	22.86	35.63	18.95	0.53	25.20	7006.46	26.60	7396.20	5.56
	3	1.30	1.24	22.86	36.82	20.21	0.55	26.61	7398.72	27.51	7648.45	3.38
	4	1.27	1.22	22.86	35.28	19.53	0.55	26.05	7242.32	27.09	7529.89	3.97
	5	1.29	1.24	22.86	36.68	19.12	0.52	25.94	7210.79	27.93	7764.49	7.68
	6	1.26	1.21	22.86	34.88	19.45	0.56	28.13	7819.99	30.58	8501.09	8.71
	7	1.30	1.24	22.86	36.71	19.87	0.54	30.14	8380.00	32.18	8946.32	6.76
	8	1.27	1.23	22.86	35.85	18.13	0.51	27.74	7712.78	29.79	8281.62	7.38
	9	1.29	1.21	22.86	35.72	19.34	0.54	27.49	7642.15	30.64	8517.48	11.45
	10	1.31	1.23	22.86	36.69	19.85	0.54	26.61	7398.72	29.21	8120.18	9.75
	11	1.29	1.23	22.86	36.04	20.01	0.56	26.45	7352.05	27.36	7605.57	3.45
	12	1.27	1.23	22.86	35.66	19.90	0.56	23.79	6612.94	26.08	7249.89	9.63
	13	1.31	1.22	22.86	36.39	18.89	0.52	29.07	8082.34	29.97	8330.81	3.07
	14	1.27	1.22	22.86	35.37	19.33	0.55	28.52	7929.72	31.62	8791.18	10.86
	15	1.29	1.24	22.86	36.63	18.93	0.52	28.66	7968.82	30.15	8382.53	5.19
Average									**7552.51**		**8064.43**	**6.78**
Stdev									**452.63**		**522.38**	**2.83**

Table 13 continued

R1M20	16	1.27	1.24	22.86	35.80	18.80	0.53	25.92	7207.00	26.83	7458.00	3.48
	17	1.27	1.23	22.86	35.62	18.93	0.53	27.08	7528.63	28.44	7905.76	5.01
	18	1.29	1.25	22.86	36.72	20.00	0.54	25.19	7002.68	27.24	7574.04	8.16
	19	13.02	1.22	22.86	362.52	18.77	0.05	26.69	7418.90	27.49	7642.15	3.01
	20	1.27	1.22	22.86	35.31	19.63	0.56	26.76	7439.08	28.71	7982.70	7.31
	21	1.25	1.24	22.86	35.32	19.14	0.54	29.38	8166.84	32.21	8953.89	9.64
	22	1.31	1.31	22.86	38.93	19.86	0.51	28.86	8024.32	30.60	8506.13	6.00
	23	1.29	1.22	22.86	35.92	19.62	0.55	27.61	7676.20	30.50	8478.38	10.45
	24	1.29	1.23	22.86	36.13	19.44	0.54	27.73	7710.26	29.54	8212.25	6.51
	25	1.30	1.23	22.86	36.43	19.84	0.54	36.50	10148.33	39.61	11011.05	8.50
	26	1.28	1.22	22.86	35.73	19.89	0.56	29.91	8315.68	30.37	8444.33	1.55
	27	1.27	1.22	22.86	35.48	18.59	0.52	32.42	9013.17	36.32	10096.62	12.02
	28	1.22	1.22	22.86	33.91	18.44	0.54	26.27	7302.86	28.01	7787.20	6.63
	29	1.21	1.22	22.86	33.69	18.54	0.55	26.64	7406.29	27.17	7553.86	1.99
	30	1.29	1.23	22.86	36.10	18.33	0.51	33.18	9223.80	34.46	9579.49	3.86
Average									**7972.27**		**8479.06**	**6.27**
Stdev									**877.55**		**1035.40**	**3.14**

Table 13 continued

R1M30	31	1.22	1.13	22.86	31.52	16.35	0.52	26.55	7379.80	28.35	7881.79	6.80
	32	1.28	1.22	22.86	35.55	19.74	0.56	28.41	7899.45	31.26	8690.28	10.01
	33	1.26	1.22	22.86	35.17	18.37	0.52	27.46	7634.58	29.75	8270.27	8.33
	34	1.30	1.23	22.86	36.47	20.34	0.56	29.04	8072.25	31.84	8850.46	9.64
	35	1.28	1.22	22.86	35.82	20.12	0.56	28.34	7879.27	29.46	8189.55	3.94
	36	1.30	1.23	22.86	36.64	20.61	0.56	26.76	7439.08	28.90	8033.15	7.99
	37	1.28	1.22	22.86	35.72	20.21	0.57	27.45	7630.80	28.83	8014.23	5.02
	38	1.29	1.22	22.86	35.92	18.53	0.52	26.33	7320.52	28.31	7869.18	7.49
	39	1.26	1.22	22.86	35.12	18.38	0.52	30.33	8431.72	31.48	8750.82	3.78
	40	1.29	1.24	22.86	36.42	19.29	0.53	25.32	7039.25	26.42	7345.75	4.35
	41	1.26	1.22	22.86	35.05	18.76	0.54	26.54	7378.54	28.43	7904.50	7.13
	42	1.31	1.24	22.86	36.98	20.99	0.57	29.06	8078.55	30.79	8560.37	5.96
	43	1.28	1.22	22.86	35.81	18.92	0.53	26.26	7300.34	28.75	7992.79	9.49
	44	1.28	1.22	22.86	35.84	20.35	0.57	25.99	7225.92	27.45	7630.80	5.60
	45	1.26	1.24	22.86	35.63	19.88	0.56	29.64	8241.26	31.01	8620.91	4.61
Average									**7663.42**		**8173.66**	**6.68**
Stdev									**414.92**		**441.23**	**2.12**

Table 13 continued

R1A	46	1.28	1.23	22.86	35.79	19.98	0.56	27.07	7524.85	27.94	7767.02	3.22
	47	1.29	1.23	22.86	36.22	18.79	0.52	27.48	7638.36	28.57	7942.34	3.98
	48	1.26	1.24	22.86	35.69	18.89	0.53	29.21	8120.18	29.94	8324.51	2.52
	49	1.29	1.23	22.86	36.19	18.40	0.51	31.15	8660.01	31.77	8832.81	2.00
	50	1.32	1.22	22.86	36.67	19.62	0.53	30.40	8451.90	31.53	8765.96	3.72
	51	1.30	1.24	22.86	36.62	18.91	0.52	27.60	7672.42	29.11	8092.43	5.47
	52	1.30	1.23	22.86	36.61	20.78	0.57	33.75	9382.73	35.85	9965.44	6.21
	53	1.29	1.24	22.86	36.39	20.11	0.55	26.62	7401.24	29.07	8081.08	9.19
	54	1.30	1.23	22.86	36.70	20.46	0.56	30.91	8593.16	31.36	8719.29	1.47
	55	1.29	1.22	22.86	36.10	18.73	0.52	25.02	6956.01	26.08	7249.89	4.22
	56	1.27	1.22	22.86	35.25	19.88	0.56	26.98	7500.88	29.20	8118.92	8.24
	57	1.29	1.23	22.86	36.16	18.77	0.52	25.71	7147.72	28.59	7947.38	11.19
	58	1.29	1.24	22.86	36.68	21.17	0.58	28.60	7949.90	29.11	8093.69	1.81
	59	1.29	1.23	22.86	36.38	19.94	0.55	29.39	8170.63	32.33	8986.68	9.99
	60	1.29	1.23	22.86	36.21	20.21	0.56	25.16	6993.85	27.54	7657.28	9.49
Average									**7877.59**		**8302.98**	**5.51**
Stdev									**687.91**		**662.30**	**3.31**

Table 13 continued

R2M10	61	1.29	1.22	22.86	36.04	20.65	0.57	26.26	7301.60	27.49	7642.15	4.66
	62	1.29	1.23	22.86	36.30	20.57	0.57	25.73	7154.03	26.88	7473.14	4.46
	63	1.30	1.23	22.86	36.53	20.65	0.57	27.70	7700.17	29.07	8081.08	4.95
	64	1.30	1.24	22.86	36.94	19.79	0.54	26.61	7397.46	27.68	7693.86	4.01
	65	1.28	1.24	22.86	36.26	19.79	0.55	31.56	8773.52	35.55	9883.46	12.65
	66	1.23	1.22	22.86	34.42	19.77	0.57	27.29	7587.91	28.17	7831.34	3.21
	67	1.26	1.23	22.86	35.26	19.67	0.56	30.89	8588.12	35.18	9780.03	13.88
	68	1.29	1.23	22.86	36.45	19.76	0.54	27.15	7548.81	28.37	7888.10	4.49
	69	1.29	1.23	22.86	36.10	20.76	0.58	28.60	7949.90	30.73	8543.97	7.47
	70	1.26	1.24	22.86	35.60	18.88	0.53	28.21	7842.69	29.28	8140.36	3.80
	71	1.30	1.23	22.86	36.55	20.99	0.57	33.26	9247.77	34.62	9623.63	4.06
	72	1.30	1.21	22.86	35.99	19.91	0.55	27.21	7563.95	28.96	8052.07	6.45
	73	1.26	1.22	22.86	35.08	20.45	0.58	26.40	7338.18	28.26	7855.31	7.05
	74	1.27	1.22	22.86	35.36	20.48	0.58	30.40	8451.90	31.67	8803.80	4.16
	75	1.27	1.23	22.86	35.59	19.23	0.54	26.84	7460.52	27.54	7657.28	2.64
Average									**7860.44**		**8329.97**	**5.86**
Stdev									**620.45**		**818.04**	**3.30**

Table 13 continued

R2M20	76	1.28	1.22	22.86	35.73	19.08	0.53	26.35	7324.30	27.65	7687.55	4.96
	77	1.29	1.22	22.86	35.86	19.30	0.54	25.87	7193.13	27.79	7726.65	7.42
	78	1.27	1.23	22.86	35.45	20.66	0.58	24.91	6924.48	25.86	7188.08	3.81
	79	1.22	1.21	22.86	33.86	19.79	0.58	25.88	7195.65	26.88	7473.14	3.86
	80	1.22	1.23	22.86	34.28	18.75	0.55	25.17	6997.63	26.89	7476.92	6.85
	81	1.29	1.22	22.86	35.98	20.05	0.56	33.34	9267.95	37.61	10456.08	12.82
	82	1.30	1.23	22.86	36.61	18.81	0.51	25.86	7188.08	26.73	7430.25	3.37
	83	1.29	1.23	22.86	36.10	19.67	0.55	26.58	7389.89	27.96	7773.32	5.19
	84	1.26	1.23	22.86	35.40	19.67	0.56	27.63	7682.51	29.90	8311.89	8.19
	85	1.29	1.23	22.86	36.27	20.21	0.56	30.96	8607.03	33.32	9264.17	7.63
	86	1.24	1.21	22.86	34.41	19.80	0.58	27.36	7605.57	31.67	8803.80	15.75
	87	1.28	1.23	22.86	35.99	19.65	0.55	26.85	7465.57	27.92	7761.97	3.97
	88	1.29	1.23	22.86	36.19	20.32	0.56	25.28	7027.90	27.17	7552.60	7.47
	89	1.30	1.23	22.86	36.44	20.43	0.56	29.54	8212.25	30.74	8545.23	4.05
	90	1.22	1.22	22.86	34.11	18.47	0.54	26.11	7257.46	26.87	7470.61	2.94
Average									**7555.96**		**8061.48**	**6.55**
Stdev									**657.35**		**882.78**	**3.63**

Table 13 continued

R2M30	91	1.24	1.22	22.86	34.58	19.76	0.57	26.49	7363.40	28.18	7833.86	6.39
	92	1.25	1.23	22.86	35.09	18.84	0.54	23.20	6450.23	25.55	7102.32	10.11
	93	1.29	1.22	22.86	36.03	20.66	0.57	31.81	8844.16	33.21	9232.63	4.39
	94	1.29	1.23	22.86	36.24	19.84	0.55	25.03	6958.53	28.40	7894.41	13.45
	95	1.28	1.23	22.86	36.10	18.97	0.53	25.47	7079.61	26.76	7440.34	5.10
	96	1.28	1.23	22.86	35.90	19.86	0.55	25.09	6974.93	26.51	7370.97	5.68
	97	1.30	1.22	22.86	36.23	20.78	0.57	28.43	7904.50	29.81	8286.67	4.83
	98	1.31	1.24	22.86	37.04	19.38	0.52	26.15	7268.81	28.41	7899.45	8.68
	99	1.32	1.23	22.86	37.29	19.67	0.53	29.68	8251.35	31.82	8846.68	7.21
	100	1.24	1.23	22.86	34.84	18.02	0.52	26.57	7386.11	28.96	8050.81	9.00
	101	1.29	1.24	22.86	36.42	19.31	0.53	24.96	6938.35	27.41	7620.71	9.83
	102	1.28	1.22	22.86	35.90	19.26	0.54	25.44	7072.05	27.46	7633.32	7.94
	103	1.24	1.24	22.86	35.29	18.48	0.52	26.99	7504.67	29.31	8147.93	8.57
	104	1.29	1.24	22.86	36.48	19.56	0.54	26.07	7247.37	27.24	7571.52	4.47
	105	1.28	1.23	22.86	35.84	20.11	0.56	30.41	8453.16	32.90	9146.87	8.21
Average									**7446.48**		**8005.23**	**7.59**
Stdev									**648.93**		**637.14**	**2.53**

Table 13 continued

R2A	106	1.27	1.22	22.86	35.54	19.93	0.56	25.92	7205.74	27.60	7673.68	6.49
	107	1.28	1.24	22.86	36.05	19.88	0.55	25.65	7130.07	27.92	7760.71	8.84
	108	1.30	1.23	22.86	36.52	19.32	0.53	27.09	7532.42	27.38	7613.14	1.07
	109	1.29	1.23	22.86	36.33	20.31	0.56	28.67	7970.08	30.66	8522.53	6.93
	110	1.28	1.23	22.86	35.93	20.18	0.56	26.46	7355.84	27.32	7594.22	3.24
	111	1.29	1.22	22.86	35.92	20.35	0.57	26.07	7247.37	27.10	7534.94	3.97
	112	1.27	1.22	22.86	35.36	19.90	0.56	25.33	7041.78	26.82	7455.48	5.87
	113	1.32	1.23	22.86	37.06	20.15	0.54	31.94	8878.21	33.06	9189.75	3.51
	114	1.31	1.22	22.86	36.59	21.21	0.58	26.55	7381.06	27.22	7566.47	2.51
	115	1.30	1.23	22.86	36.55	19.99	0.55	27.91	7759.45	29.40	8174.41	5.35
	116	1.30	1.22	22.86	36.06	19.93	0.55	25.99	7225.92	27.07	7524.85	4.14
	117	1.29	1.23	22.86	36.04	18.53	0.51	25.53	7097.27	28.20	7838.91	10.45
	118	1.27	1.23	22.86	35.77	18.71	0.52	25.89	7198.17	27.57	7663.59	6.47
	119	1.29	1.23	22.86	36.24	20.16	0.56	27.98	7778.37	29.68	8250.09	6.06
	120	1.28	1.23	22.86	35.90	19.38	0.54	25.33	7043.04	25.65	7130.07	1.24
Average									**7456.32**		**7832.86**	**5.08**
Stdev									**486.02**		**511.50**	**2.64**

Table 14. Destructive MOE and MOR

Where 't' is thickness, 'w' width, 'l' length, 'SG' is specific gravity (dry weight/ volume)

Treatment	Sample	t (cm)	w (cm)	l (cm)	V (cm3)	Dry weight (g)	SG	MOE (M Pa)	MOR (M Pa)
R1M10	1	1.288	1.232	22.86	36.27	20.13	0.55	9206.01	123.35
	2	1.265	1.232	22.86	35.63	18.95	0.53	9790.62	102.80
	3	1.298	1.241	22.86	36.82	20.21	0.55	9021.78	102.25
	4	1.267	1.218	22.86	35.28	19.53	0.55	9481.59	97.63
	5	1.294	1.24	22.86	36.68	19.12	0.52	12543.85	115.21
	6	1.257	1.214	22.86	34.88	19.45	0.56	10486.23	96.80
	7	1.297	1.238	22.86	36.71	19.87	0.54	10387.91	99.97
	8	1.272	1.233	22.86	35.85	18.13	0.51	11552.86	93.36
	9	1.287	1.214	22.86	35.72	19.34	0.54	9896.18	103.84
	10	1.308	1.227	22.86	36.69	19.85	0.54	10936.53	93.77
	11	1.287	1.225	22.86	36.04	20.01	0.56	9352.80	99.15
	12	1.265	1.233	22.86	35.66	19.90	0.56	9292.12	103.08
	13	1.308	1.217	22.86	36.39	18.89	0.52	10951.22	104.11
	14	1.265	1.223	22.86	35.37	19.33	0.55	9817.51	107.63
	15	1.288	1.244	22.86	36.63	18.93	0.52	10155.28	103.08
Average								**10191.50**	**103.07**
Stdev								**977.95**	**7.82**

Table 14 continued

R1M20	16	1.267	1.236	22.86	35.80	18.80	0.53	10228.44	93.15
	17	1.271	1.226	22.86	35.62	18.93	0.53	9605.63	92.94
	18	1.287	1.248	22.86	36.72	20.00	0.54	10028.49	100.94
	19	1.302	1.1218	22.86	33.39	18.77	0.56	10441.28	94.60
	20	1.268	1.218	22.86	35.31	19.63	0.56	9942.44	105.42
	21	1.25	1.236	22.86	35.32	19.14	0.54	11478.74	107.97
	22	1.305	1.305	22.86	38.93	19.86	0.51	9348.94	96.46
	23	1.287	1.221	22.86	35.92	19.62	0.55	10041.72	118.59
	24	1.286	1.229	22.86	36.13	19.44	0.54	11725.16	99.97
	25	1.301	1.225	22.86	36.43	19.84	0.54	12316.46	99.63
	26	1.28	1.221	22.86	35.73	19.89	0.56	10005.11	112.32
	27	1.27	1.222	22.86	35.48	18.59	0.52	10227.06	108.46
	28	1.218	1.218	22.86	33.91	18.44	0.54	9916.03	92.74
	29	1.213	1.215	22.86	33.69	18.54	0.55	9028.74	107.42
	30	1.286	1.228	22.86	36.10	18.33	0.51	10193.96	119.35
Average								**10301.88**	**103.33**
Stdev								**887.76**	**8.93**

Table 14 continued

R1M30	31	1.218	1.132	22.86	31.52	16.35	0.52	8728.68	95.70
	32	1.279	1.216	22.86	35.55	19.74	0.56	11806.31	99.77
	33	1.257	1.224	22.86	35.17	18.37	0.52	10056.07	100.39
	34	1.296	1.231	22.86	36.47	20.34	0.56	10833.94	106.11
	35	1.28	1.224	22.86	35.82	20.12	0.56	9582.26	109.97
	36	1.303	1.23	22.86	36.64	20.61	0.56	9628.52	101.22
	37	1.284	1.217	22.86	35.72	20.21	0.57	9989.88	111.83
	38	1.288	1.22	22.86	35.92	18.53	0.52	9867.36	99.29
	39	1.255	1.224	22.86	35.12	18.38	0.52	11635.66	101.01
	40	1.288	1.237	22.86	36.42	19.29	0.53	10020.70	101.84
	41	1.261	1.216	22.86	35.05	18.76	0.54	10235.33	111.01
	42	1.31	1.235	22.86	36.98	20.99	0.57	11111.80	96.80
	43	1.281	1.223	22.86	35.81	18.92	0.53	10369.37	97.77
	44	1.281	1.224	22.86	35.84	20.35	0.57	10564.01	109.21
	45	1.26	1.237	22.86	35.63	19.88	0.56	11533.76	100.39
Average								**10397.57**	**102.82**
Stdev								**858.20**	**5.37**

Table 14 continued

R1A	46	1.276	1.227	22.86	35.79	19.98	0.56	9539.30	108.04
	47	1.286	1.232	22.86	36.22	18.79	0.52	8910.56	111.14
	48	1.262	1.237	22.86	35.69	18.89	0.53	9768.76	112.59
	49	1.287	1.23	22.86	36.19	18.40	0.51	10347.99	97.35
	50	1.315	1.22	22.86	36.67	19.62	0.53	11546.38	104.87
	51	1.297	1.235	22.86	36.62	18.91	0.52	10333.93	100.80
	52	1.301	1.231	22.86	36.61	20.78	0.57	10020.21	115.76
	53	1.287	1.237	22.86	36.39	20.11	0.55	10782.16	99.70
	54	1.301	1.234	22.86	36.70	20.46	0.56	9728.70	92.53
	55	1.29	1.224	22.86	36.10	18.73	0.52	10020.35	84.74
	56	1.267	1.217	22.86	35.25	19.88	0.56	9875.63	115.49
	57	1.287	1.229	22.86	36.16	18.77	0.52	10508.99	90.46
	58	1.294	1.24	22.86	36.68	21.17	0.58	8568.86	111.83
	59	1.294	1.23	22.86	36.38	19.94	0.55	11679.17	105.28
	60	1.292	1.226	22.86	36.21	20.21	0.56	9872.60	110.94
Average								**10100.24**	**104.10**
Stdev								**835.40**	**9.57**

Table 14 continued

R2M10	61	1.288	1.224	22.86	36.04	20.65	0.57	10116.60	116.38
	62	1.289	1.232	22.86	36.30	20.57	0.57	10993.76	107.70
	63	1.296	1.233	22.86	36.53	20.65	0.57	11941.38	107.28
	64	1.303	1.24	22.86	36.94	19.79	0.54	7774.30	95.49
	65	1.278	1.241	22.86	36.26	19.79	0.55	11757.70	105.15
	66	1.234	1.22	22.86	34.42	19.77	0.57	12333.28	117.28
	67	1.258	1.226	22.86	35.26	19.67	0.56	11428.13	114.04
	68	1.292	1.234	22.86	36.45	19.76	0.54	10732.24	109.49
	69	1.288	1.226	22.86	36.10	20.76	0.58	11033.06	109.70
	70	1.257	1.239	22.86	35.60	18.88	0.53	10945.50	114.25
	71	1.303	1.227	22.86	36.55	20.99	0.57	10933.77	117.76
	72	1.297	1.214	22.86	35.99	19.91	0.55	10586.97	100.60
	73	1.262	1.216	22.86	35.08	20.45	0.58	10021.59	120.11
	74	1.267	1.221	22.86	35.36	20.48	0.58	10056.07	110.25
	75	1.27	1.226	22.86	35.59	19.23	0.54	11138.55	108.18
Average								**10786.19**	**110.24**
Stdev								**1070.36**	**6.70**

Table 14 continued

R2M20	76	1.28	1.221	22.86	35.73	19.08	0.53	11117.87	114.25
	77	1.291	1.215	22.86	35.86	19.30	0.54	11344.91	102.46
	78	1.266	1.225	22.86	35.45	20.66	0.58	10273.05	118.52
	79	1.223	1.211	22.86	33.86	19.79	0.58	10242.23	116.04
	80	1.224	1.225	22.86	34.28	18.75	0.55	9208.83	90.25
	81	1.289	1.221	22.86	35.98	20.05	0.56	12112.65	110.52
	82	1.3	1.232	22.86	36.61	18.81	0.51	9890.59	91.36
	83	1.288	1.226	22.86	36.10	19.67	0.55	9260.82	103.63
	84	1.256	1.233	22.86	35.40	19.67	0.56	11412.00	114.80
	85	1.29	1.23	22.86	36.27	20.21	0.56	11418.27	119.83
	86	1.244	1.21	22.86	34.41	19.80	0.58	11682.89	120.18
	87	1.284	1.226	22.86	35.99	19.65	0.55	9103.14	114.32
	88	1.288	1.229	22.86	36.19	20.32	0.56	11481.43	115.21
	89	1.297	1.229	22.86	36.44	20.43	0.56	12126.30	115.07
	90	1.221	1.222	22.86	34.11	18.47	0.54	10005.04	104.53
Average								**10712.00**	**110.06**
Stdev								**1055.35**	**9.59**

Table 14 continued

R2M30	91	1.24	1.22	22.86	34.58	19.76	0.57	12119.47	118.87
	92	1.245	1.233	22.86	35.09	18.84	0.54	10021.59	107.83
	93	1.291	1.221	22.86	36.03	20.66	0.57	12139.54	118.04
	94	1.29	1.229	22.86	36.24	19.84	0.55	10514.43	112.32
	95	1.283	1.231	22.86	36.10	18.97	0.53	9942.92	102.73
	96	1.281	1.226	22.86	35.90	19.86	0.55	9988.70	118.45
	97	1.296	1.223	22.86	36.23	20.78	0.57	9542.61	123.42
	98	1.31	1.237	22.86	37.04	19.38	0.52	9563.98	102.59
	99	1.322	1.234	22.86	37.29	19.67	0.53	10658.81	100.46
	100	1.24	1.229	22.86	34.84	18.02	0.52	9679.89	103.97
	101	1.29	1.235	22.86	36.42	19.31	0.53	9473.94	101.97
	102	1.283	1.224	22.86	35.90	19.26	0.54	10022.28	101.28
	103	1.243	1.242	22.86	35.29	18.48	0.52	9850.05	102.73
	104	1.292	1.235	22.86	36.48	19.56	0.54	8592.37	105.28
	105	1.28	1.225	22.86	35.84	20.11	0.56	10173.69	108.80
Average								**10152.29**	**108.58**
Stdev								**934.94**	**7.68**

Table 14 continued

R2A	106	1.27	1.224	22.86	35.54	19.93	0.56	10414.18	115.49
	107	1.277	1.235	22.86	36.05	19.88	0.55	10159.49	109.01
	108	1.304	1.225	22.86	36.52	19.32	0.53	8908.63	102.46
	109	1.292	1.23	22.86	36.33	20.31	0.56	11143.72	116.45
	110	1.28	1.228	22.86	35.93	20.18	0.56	9847.22	106.25
	111	1.286	1.222	22.86	35.92	20.35	0.57	9203.66	119.42
	112	1.271	1.217	22.86	35.36	19.90	0.56	9801.65	105.97
	113	1.319	1.229	22.86	37.06	20.15	0.54	12056.80	107.56
	114	1.31	1.222	22.86	36.59	21.21	0.58	10781.95	110.25
	115	1.3	1.23	22.86	36.55	19.99	0.55	8983.37	108.25
	116	1.295	1.218	22.86	36.06	19.93	0.55	10256.84	112.73
	117	1.286	1.226	22.86	36.04	18.53	0.51	11542.38	101.15
	118	1.272	1.23	22.86	35.77	18.71	0.52	10867.86	106.32
	119	1.292	1.227	22.86	36.24	20.16	0.56	9189.11	105.63
	120	1.28	1.227	22.86	35.90	19.38	0.54	9089.28	108.52
Average								**10149.74**	**109.03**
Stdev								**986.23**	**5.10**

Table 15. Color change of sample after ACQ type C and post treatments

Treatment	Sample ID	Lightness L				Chromaticity a				Chromaticity b				Color change ΔE
		Initial L L_i	Final L L_f	ΔL (L_f-L_i)	Change % $\Delta L/L_i$ (%)	Initial a a_i	Final a	Δa (a_f-a_i)	Change % $\Delta a/a_i$ (%)	Initial b b_i	Final b b_f	Δb (b_f-b_i)	Change % $\Delta b/b_i$ (%)	
R1M10	5	82.62	55.68	-26.94	-32.61	5.30	1.03	-4.27	-80.56	25.78	16.78	-9.00	-34.92	28.73
	6	81.64	55.52	-26.12	-32.00	5.69	0.84	-4.85	-85.21	27.31	15.67	-11.64	-42.63	29.01
	7	82.09	54.03	-28.07	-34.19	5.95	1.29	-4.66	-78.35	28.25	16.73	-11.52	-40.77	30.70
	8	84.64	60.01	-24.63	-29.10	4.00	0.35	-3.65	-91.20	23.39	16.59	-6.79	-29.05	25.81
Average		**82.75**	**56.31**	**-26.44**	**-31.97**	**5.23**	**0.88**	**-4.36**	**-83.83**	**26.18**	**16.44**	**-9.74**	**-36.84**	**28.56**
Stdev		**1.32**	**2.58**	**1.45**	**2.13**	**0.87**	**0.40**	**0.53**	**5.69**	**2.12**	**0.52**	**2.31**	**6.15**	**2.03**
R1M20	9	78.20	54.86	-23.33	-29.84	7.09	1.80	-5.30	-74.70	26.44	18.73	-7.71	-29.17	25.14
	10	84.33	56.65	-27.68	-32.82	4.17	0.26	-3.91	-93.81	25.13	16.69	-8.44	-33.59	29.20
	11	81.87	57.92	-23.95	-29.26	5.24	1.20	-4.03	-77.04	26.03	18.24	-7.79	-29.94	25.51
	12	81.72	54.56	-27.16	-33.23	5.21	1.45	-3.76	-72.25	25.27	16.72	-8.55	-33.84	28.72
Average		**81.53**	**56.00**	**-25.53**	**-31.29**	**5.43**	**1.18**	**-4.25**	**-79.45**	**25.72**	**17.59**	**-8.12**	**-31.63**	**27.14**
Stdev		**2.52**	**1.58**	**2.21**	**2.03**	**1.22**	**0.66**	**0.71**	**9.77**	**0.62**	**1.05**	**0.43**	**2.43**	**2.11**
R1M30	13	79.24	56.34	-22.90	-28.90	6.47	1.72	-4.75	-73.47	26.78	17.83	-8.95	-33.42	25.04
	14	80.46	55.86	-24.60	-30.57	6.37	1.11	-5.26	-82.55	28.14	16.53	-11.61	-41.24	27.70
	15	80.85	53.99	-26.86	-33.22	5.90	1.25	-4.65	-78.81	28.43	16.27	-12.16	-42.79	29.85
	16	78.24	54.49	-23.75	-30.35	7.33	1.38	-5.95	-81.19	29.78	15.87	-13.91	-46.71	28.16
Average		**79.70**	**55.17**	**-24.53**	**-30.76**	**6.52**	**1.36**	**-5.15**	**-79.01**	**28.28**	**16.62**	**-11.66**	**-41.04**	**27.69**
Stdev		**1.19**	**1.11**	**1.70**	**1.80**	**0.60**	**0.26**	**0.59**	**4.00**	**1.23**	**0.85**	**2.06**	**5.58**	**1.99**

Table 15 continued

R1A	1	79.97	55.95	-24.03	-30.05	6.19	1.00	-5.19	-83.79	27.19	17.68	-9.51	-34.96	26.36
	2	83.17	56.16	-27.01	-32.47	5.23	0.68	-4.55	-87.08	26.65	17.41	-9.25	-34.69	28.91
	3	80.28	53.68	-26.60	-33.14	5.76	1.29	-4.48	-77.69	25.73	16.98	-8.75	-34.01	28.36
	4	83.82	57.53	-26.29	-31.37	4.90	0.61	-4.28	-87.47	26.42	17.33	-9.10	-34.43	28.15
Average		**81.81**	**55.83**	**-25.98**	**-31.76**	**5.52**	**0.89**	**-4.63**	**-84.01**	**26.50**	**17.35**	**-9.15**	**-34.52**	**27.94**
Stdev		**1.97**	**1.60**	**1.34**	**1.35**	**0.57**	**0.31**	**0.39**	**4.52**	**0.61**	**0.29**	**0.32**	**0.41**	**1.11**
R2M10	25	83.40	51.73	-31.67	-37.97	4.75	-0.68	-5.43	-114.27	26.18	15.99	-10.19	-38.94	33.71
	26	83.68	53.70	-29.98	-35.82	4.69	-1.11	-5.80	-123.71	25.83	15.73	-10.10	-39.11	32.16
	27	82.02	54.12	-27.90	-34.01	5.27	-0.52	-5.79	-109.86	26.75	16.82	-9.94	-37.14	30.18
	28	81.99	50.17	-31.82	-38.80	5.16	0.16	-5.00	-96.86	26.16	16.39	-9.77	-37.34	33.66
Average		**82.78**	**52.43**	**-30.34**	**-36.65**	**4.97**	**-0.54**	**-5.50**	**-111.18**	**26.23**	**16.23**	**-10.00**	**-38.13**	**32.43**
Stdev		**0.89**	**1.83**	**1.83**	**2.16**	**0.29**	**0.53**	**0.38**	**11.16**	**0.38**	**0.48**	**0.19**	**1.03**	**1.66**
R2M20	29	84.60	54.52	-30.08	-35.56	3.80	-0.57	-4.37	-115.12	24.07	16.94	-7.13	-29.64	31.22
	30	81.73	50.54	-31.19	-38.16	5.31	0.52	-4.78	-90.13	26.00	15.08	-10.92	-42.01	33.39
	31	80.62	49.93	-30.69	-38.06	6.19	0.65	-5.54	-89.48	27.86	16.91	-10.95	-39.32	33.05
	32	81.06	52.08	-28.98	-35.75	5.60	-0.18	-5.78	-103.19	27.16	16.75	-10.41	-38.34	31.33
Average		**82.00**	**51.77**	**-30.23**	**-36.88**	**5.22**	**0.11**	**-5.12**	**-99.48**	**26.27**	**16.42**	**-9.86**	**-37.33**	**32.25**
Stdev		**1.79**	**2.05**	**0.95**	**1.42**	**1.02**	**0.58**	**0.65**	**12.19**	**1.66**	**0.90**	**1.83**	**5.36**	**1.13**

Table 15 continued

R2M30	33	82.92	49.64	-33.28	-40.13	4.48	0.06	-4.42	-98.63	24.99	15.33	-9.66	-38.64	34.93
	34	83.45	53.04	-30.40	-36.44	4.53	-0.19	-4.72	-104.18	24.93	15.88	-9.05	-36.32	32.07
	35	82.99	46.73	-36.26	-43.69	4.63	0.87	-3.76	-81.18	26.01	15.74	-10.28	-39.51	37.87
	36	85.40	53.52	-31.88	-37.33	3.68	-0.68	-4.36	-118.53	24.18	16.44	-7.74	-32.01	33.10
Average		**83.69**	**50.73**	**-32.95**	**-39.40**	**4.33**	**0.02**	**-4.31**	**-100.63**	**25.03**	**15.85**	**-9.18**	**-36.62**	**34.49**
Stdev		**1.17**	**3.18**	**2.49**	**3.27**	**0.44**	**0.65**	**0.40**	**15.44**	**0.75**	**0.46**	**1.08**	**3.35**	**2.54**
R2A	21	80.80	53.96	-26.84	-33.21	6.38	0.32	-6.05	-94.93	28.72	17.81	-10.91	-38.00	29.60
	22	83.59	54.53	-29.07	-34.77	4.53	-0.46	-4.99	-110.13	25.89	17.64	-8.25	-31.85	30.62
	23	81.68	50.72	-30.96	-37.90	5.81	-0.03	-5.84	-100.53	27.50	16.03	-11.46	-41.69	33.53
	24	83.83	50.19	-33.64	-40.13	4.62	-1.37	-5.99	-129.67	26.29	16.75	-9.54	-36.29	35.48
Average		**82.47**	**52.35**	**-30.13**	**-36.51**	**5.33**	**-0.38**	**-5.72**	**-108.81**	**27.10**	**17.06**	**-10.04**	**-36.96**	**32.31**
Stdev		**1.47**	**2.21**	**2.89**	**3.11**	**0.91**	**0.73**	**0.49**	**15.26**	**1.28**	**0.83**	**1.44**	**4.08**	**2.69**

Statistical analysis

1. Copper leaching

Independent variables:

a) ACQ treating solution at two concentration R1=0.5% and R2=0.8%

b) Post treatments:

Microwavaing at different durations, 0 min, 10 min, 20 min and 30 min

Air drying for 21 days

Dependendent variable: Amount of copper leached in mg

Source	DF	Type 3 SS	Mean square	F value	Pr > F
ACQ solution	1.00	318.79	318.79	890.17	<.0001
Post treatments	4.00	1145.14	286.28	799.40	<.0001
ACQ solution * Post treatments	4.00	42.64	10.66	29.77	<.0001

Multiple comparisons of treatments

ACQ solution	Post treatments	Copper leached LS means	LS mean number
R1	0 min microwave	33.15	1
R1	10 min microwave	26.83	2
R1	20 min microwave	17.08	3
R1	30 min microwave	12.86	4
R1	21 days air dry	16.69	5
R2	0 min microwave	41.92	6
R2	10 min microwave	32.27	7
R2	20 min microwave	30.43	8
R2	30 min microwave	19.5	9
R2	21 days air dry	22.43	10

For the effect of ACQ solution * Post treatments										
Pr > t for H0: LS means (i) = LS means (j)										
Dependent variable : copper										
i/j	1	2	3	4	5	6	7	8	9	10
1		<.0001	<.0001	<.0001	<.0001	<.0001	0.8723	0.0204	<.0001	<.0001
2	<.0001		<.0001	<.0001	<.0001	<.0001	0.0002	0.0033	<.0001	0.0004
3	<.0001	<.0001		0.0006	0.9994	<.0001	<.0001	<.0001	0.0427	0.0002
4	<.0001	<.0001	0.0006		0.0021	<.0001	<.0001	<.0001	<.0001	<.0001
5	<.0001	<.0001	0.9994	<.0021		<.0001	<.0001	<.0001	0.0170	<.0001
6	<.0001	<.0001	<.0001	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001
7	<.8725	0.0002	<.0001	<.0001	<.0001	<.0001		0.1675	<.0001	<.0001
8	<.0204	0.0033	<.0001	<.0001	<.0001	<.0001	0.1675		<.0001	<.0001
9	<.0001	<.0001	<.0427	<.0001	0.0170	<.0001	<.0001	<.0001		0.0125
10	<.0001	0.0004	0.0002	<.0001	<.0001	<.0001	<.0001	<.0001	0.0125	

2. Non destructive MOE

Independent variables:

a) ACQ treating solution at two concentration R1=0.5% and R2=0.8%

b) Post treatments:

Microwavaing at different durations 10 min, 20 min and 30 min

Air drying for 21 days

Dependendent variable: Non destructive MOE.

* Square root transformation of the non- destructive MOE difference (before and after ACQ and post treatments) was used for the analysis.

Type 3 Test of fixed effect			
Effect	Numerator DF	Denominator DF	Pr > F
ACQ solution	1	112	0.7531
Post treatment	3	112	0.0733
ACQ solution * Post treatment	3	112	0.825

3. Destructive MOE

Independent variables:

a) ACQ treating solution at two concentration R1=0.5% and R2=0.8%

b) Post treatments:

Microwaving at different durations 10 min, 20 min and 30 min

Air drying for 21 days

Dependendent variable: Destructive MOE.

* MOE of the control samples which is neither ACQ treated nor post treated also taken in account for the analysis.

Source	DF	Type 3 SS	Mean square	F value	Pr > F
ACQ solution	2	1293401.529	646700.764	0.72	0.491
Post treatments	3	3005046.804	1001682.268	1.11	0.3485
ACQ solution * Post treatments	3	3156345.263	1052115.088	1.16	0.3263

4. Destructive MOR

Independent variables:

a) ACQ treating solution at two concentration R1=0.5% and R2=0.8%

b) Post treatments:

Microwaving at different durations 10 min, 20 min and 30 min

Air drying for 21 days

Dependendent variable: Destructive MOE.

* MOR of the control samples which is neither ACQ treated nor post treated also taken in account for the analysis.

Source	DF	Type 3 SS	Mean square	F value	Pr > F
ACQ solution	2	1329.451373	664.725686	10.68	<.0001
Post treatments	3	20.052592	6.684197	0.11	0.9556
ACQ solution * Post treatments	3	22.766076	7.588692	0.12	0.947

4. Color change, ΔE

Independent variables:

a) ACQ treating solution at two concentration R1=0.5% and R2=0.8%

b) Post treatments:

Microwaving at different durations 10 min, 20 min and 30 min

Air drying for 21 days

Dependendent variable: Color change, ΔE

Source	DF	Type 3 SS	Mean square	F value	Pr > F
ACQ solution	1	202.7539	202.7539	51.43	<.0001
Post treatments	3	8.388654	2.796218	0.71	0.5559
ACQ solution * Post treatments	3	9.911051	3.303684	0.84	0.4863

REFERENCE

Alexander, D. L. and Cooper, P. A. 1993. Effects of temperature and humidity on CCA-C fixation in pine sap wood. Wood protection. 2(2): 39-45.

American Society for testing materials 2005. Standard test method for small clear specimen of timber, D 143-94. Annual Book of ASTM Standards. ASTM, West Conshohocken.

American Wood Preservers Association, 2005. Standards for water born preservatives, P5-05. American Wood Preservers Association standards, Granbury, Texas.

American Wood Preservers Association, 2005. Standard method of determining the leachability of wood preservatives, E11-97. American Wood Preservers Association standards, Granbury, Texas.

Anonymus, 1999.

Anderson, D. J. 1990.Accecerated fixation of chromated copper preservative treated wood. Proceedings of the annual meeting of the Ameraican Wood preserver's Association. 86: 129- 151.

Avramidis, S. and Ruddick, J. N. R. 1996. CCA accelerated fixation by dielectric heating. Forest Products Journal. 46(7/8): 52-55.

Barnes, H. M., Lyon, D. E., Zahora, A. R. and Muisu, F. 1993. Strength properties of ACQ treated southern pine lumber. Proccedings of the annual meeting of American wood preserver's association. 89: 49-53.

Bendsten, B. A., Gjovik, L. R. and Verril. 1983. The mechanical properties of salt treated longleaf pine. Res. Pap. FPL-434. USDA Forest Serv., Forest Products Laboratory., Madison, WI.

Bowyer, J. L; Shmulsky, R and Haygreen, J. G. 2003. Forest Products and Wood Science- An Introduction, Fourth Edition, Iowa State Press, Iowa.

Cao, J. and Kamdem, P. 2004. Microwave treatment to accelerate fixation of copper ethanolamine (Cu-EA) treated wood. Holzforschung. 58: 569-571.

Cao, J. and Kamdem, P. 2005. Microdistribution of copper in copper-ethanolamine (Cu-EA) treated southern yellow pine (*Pinus spp*) related to density distribution. Holzforschung. 59: 82-89.

Chen, J., Kaldes, M., Ung, Y. T. and Copper, P. A. 1994. Heat transfer and wood moisture effect in moderate temperature fixation of CCA treated wood. Do No. IRG/WP 99-40022. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Christensen, T. 1990. Industrial fixation of chromium based wood preservatives. Do No. IRG/WP/3630. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Chung, P. A. and Ruddick, J. N. R. 2004. Leaching of ACQ treated wood exposed above ground. Do No. IRG/WP 04-50219. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Collins, M. J. and Vinden, P. 1987. Strength loss associated with steam conditioning and boron treatment of radiata pine framing. Do No. IRG/WP/3438. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Conardie, W. E. and A. Pizzi. 1987. Progressive heat inactivation of CCA biological performance. Holzforshung und Holzverwertung. 39(3): 70-77.

Cooper, P. A. and Ung, T. 1989. Moderate temperature fixation of CCA-C. Do No. IRG/WP/3522. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Cooper, P. A. 1991. Cation exchange adsoption of copper on wood. Wood Protection. 1(1): 9-14.

Cooper, P. A., Y. T. Ung, and D. P. Kamdem. 1997. Fixation and leaching of CCA treated redmaple (Acer rubrum L.). Forest Products Journal . 47(2):70-74.

Corkhil, T. 1989. The Complete dictionary of Wood.

Cote, W. A. 1967. "Wood ultrastructure". University of Washington Press, Syracus, NY.

Cui, W., Girods, P., Jacqueson, A. and Kamdem, D. P. 2005. Effect of the addition of ammonia in the retention and leaching of copper amine treated southern yellow pine cubes. Forest Products Journal. 55(10): 92-94.

Dahlgren, S.E. and W.H. Hartford. 1972. Kinetics and mechanism of fixation of Cu-Cr-As wood preservatives. Part I. pH behavior and general aspects of fixation. Holzforschung. 26:62-69

Dahlgren, S.E. and W.H. Hartford. 1972. Kinetics and mechanism of fixation of Cu-Cr-As wood preservatives. Part II. Fixation of boliden K33. Holzforschung. 26: 105-113

Dahlgren, S.E. and W.H. Hartford. 1972. Kinetics and mechanism of fixation of Cu-Cr-As wood preservatives. Part III. Fixation of Tanalith C and comparison of different preservatives. Holzforschung. 26: 142-149

Druz, N., Andersone, I. and Anderson, B. 2001. Interaction of Copper-Containing Preservatives with Wood. Part 1. Mechanism of the Interaction of Copper with Cellulose. Holzforshung. 55: 13-15.

Esser, P., Suitela, W. and Trompetter, H. 2000. Copper leaching from Kemwood ACQ and Emblit CBC treated wood products. . Doc No. IRG/WP 00-50150. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Fang, F; Ruddick, J. N. R. and Avramidis, S. 2001. Application of radio frequency heating to utility poles. Part 2. Accelerated fixation of chromated copper arsenate. Forest Products Journal. 51(9): 53-58.

Hon, D. N.S and Shiraishi, N. 2000. Wood and Cellulosic chemistry, Second edition, revised and expanded. Marcel Dekker, Inc. New York.

Hon, D. N.S and Minemura, N. 2000. Color and discoloration. *In.* Wood and Cellulosic chemistry, Second edition, revised and expanded. *Ed.* Hon, D. N. S. and Shirashi, N. 2000. Marcel Dekker, Inc. New York.

Hughes, A.S., R.J. Murphy, J.F. Gibson and J.A.Cornfield. 1994. Electron paramagneticresonance spectroscopic analysis of copper based preservatives in Pinussylvestris. Holzforschung. 48: 91-98

Jiang, X. and Ruddick, J. N. R. 1999. A spectroscopic investigation of copper ethelenediamine fixation in wood.. Do No. IRG/WP/99-20160. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Jiang, X. and Ruddick, J. N. R. 2000. A comparison of the leaching resistance of copper 2 etahnolamine and copper ethylenediamine treated Scots pine. Do No. IRG/WP/00-30233. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Jin, K. and Archer, K. 1991. Copper based wood preservatives: Observation on fixation, distribution and performance. Procee. Amer. Wood Preserv. Assoc. 87: 169-184.

Jin, L. and Preston, A.F. 1993. Depletion of preservatives from treated wood: Results from Laboratory, Fungus Cellar and Field Tests. Do No. IRG/WP 93- 50001. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Kaldas, M. L. and Cooper, P. A. 1996. Effect of wood moisture content on rate of fixation and leachabilty of CCA treated redpine. Forest Product Journal. 46(10): 61-67.

Kamdem, D. P and J. Zhang. 2000 . Contribtion of wood components on the absorption of copper amine. Do No. IRG/WP/00-30216. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Kennedy, M. J and Collins, P. A. 2001. Leaching of preservative components from pine decking treated with CCA and copper azole, and interactions of leachate with soils. Do No. IRG/WP 01-50171. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden

Koch, P. 1985. Utilization of Hardwood growing on Southern pine sites. Agricultural Handbook. 605. Vol 1. USDA Forest Service, Washington, DC. Pp. 365-464.

Lebow, S. 2004. Alternatives to Chromated Copper Arsenate for Residential Construction. Res. Pap. FPL- RP-618. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 9.

Lee, A. W. C., Grafton, J. C. and Tainter, F. H. 1993. Effect of rapid redying shortly after treatment on leachabilty of CCA treated southern pine. Forest Product Journal. 43(2): 37-40.

LeVan, Susan, L., Kim, Man, W., Nagel, M., Robert, J., Evans and James, W. 1996. Mechanical properties of fire retardant treated plywood after cyclic temperature exposure. Forest Products Journal. 46 (5): 64-71.

Loubinoux, B. and Malek, H. 1992. Interaction of quaternary ammonium salts with wood. 1. Fixation of benzalkonium bromide and chloride. Holzforschung. 46: 537-539.

Loubinoux, B., Malek, H., Joly, J. P. and Kilbertus, G. 1992. Interaction of quaternary ammonium salts with wood: Influence of cation and anion structure on fixation and leaching. Forest Products Journal. 42 (10): 55-58.

Lucas, N. and Ruddick, J. N. R. 2002. Determination of the amine to copper ratio remaining in wood after water leaching. Do No. IRG/WP 02-30285. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

McNamara, W. S. 1989. CCA Fixation Experiments Part-1. Do No. IRG/WP 3504. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

McNamara, W. S. 1989. CCA Fixation Experiments Part-2. Do No. IRG/WP 3505. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Mingos, D. M. P. and Baghurst, D. R. 1997. Applications of Microwave dielectric heating effects to Synthetic Problems in Chemistry. *In.* Microwave - Enhanced Chemistry: Fundamentals, Sample preparation, and Applications. *Ed.* Kingston, H. M. and Haswell, S. J. American Chemical Society, Washington, DC.

Pasek, E. A. 2003. Minimizing preservative losses: fixation a report of the P4 migration /fixation/depletion task force. In. Proceedings, American Wood Preservers Association. 2003. 100-124.

Pizzi, A. 1983. A new approach to the formulation and application of CCA preservatives. Wood Sci. and Tech. 17: 303-319.

Pizzi, A. 1983. Practical consequences of the clarification of the chemical mechanism of CCA fixation to wood. Do No. IRG/WP/3220. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden

Rennie, P. M. S., S. M. Gray and D. J. Dickinson, 1987. Copper based water borne preservatives: copper adsorption in relation to performance against soft rot. Do No. IRG/WP 3452. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Ruddick, J. N. R. 1992. The fixation chemistry of copper based wood preservatives. Proc. Can. Wood Presev. Assoc. 13: 116-137.

Ruddick, J. N. R. 1996. The fixation chemistry of ammoniacal copper wood preservatives. Proc. Ameri. Wood Presev. Assoc. 92: 32-49.

Ruddick, J. N. R.; Xie, C. and Herring, F. G. 2001. Fixation of Aimine Copper Preservatives, Part 1. Reaction of Vannilin, a lignin Model compound with Monoethonolamine Copper Sulphate solution . Holzforzhung. 55:585-589.

Sjöström, E. 1989. The origin of charge on cellulosic fibers. Nordic Pulp and Paper Research. 2: 90-93

Sjostrom, E. 1993. Wood chemistry fundamentals and applications, Second edition Academic press.

Smith, W. B., Schneider, P. and Resch, H. 1996. Rapid fixation of CCA wood preservative with electromagnetic energy. Forest Products Journal. 46(7/8): 47-51.

Staccioli, G., Sturaro, A. and Rella, R. 2000. Cation exchange capacity tests on Some Lignocellulosic materials Highlight some aspects of the Use of Copper as Wood Preservatives. Holzforschung. 54: 133-136.

Tascioglu, C., Cooper, P. and Tony, U. 2005. Rate and extent of adsorption of ACQ preservative components in wood. Holzforschung. 59: 574-580.

Torgovnikov, G. and Vinden, P. 2000. Microwave Modification of Yellow Stringybark (Eucalyptus Muelleriana) Posts for Impregnation with Copper-Chrom-Arsenic (CCA) Preservatives.

Torgovnikov, G and Vinden, P. 2000. Microwave modification of Wood Properties: Improvements in Wood Permiability. Do No. IRG/WP 00-40181. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden

Ung, Y. T. and Cooper, P. A. 2005. Copper stabilization in ACQ-D treated wood: retention, temeperature and species effects. Holz als Roh- und Werkstoff. 63: 186-191.

Vinden, P., Torgovnikov, G. and Romero, J. 2000. Microwave conditioning of *Pinus radita* D. Don for preservative treatment. 31st Annual meeting of International Research Group on wood preservation. Doc No: IRG/WP 00-40182.

Waldron, Y. T., Ung, Y. T. and Cooper, P. A. 2003. Leaching of inorganic wood preservatives – Investigating the relationship between leachability , dissociation characteristics and long-term leaching potentials. 34th Annual meeting of International Research Group on wood preservation. Doc No: IRG/WP 03-50199.

Watkinson, P. J. and Van Gosliga. Effect of humidity on physical and mechanical properties of New Zealand wood composites. Forest Products Journal. 40 (7/8): 15-20.

Winandy, J. E., Boon, R. S. and Bendsten, B. A. 1985. The Interaction of CCA preservative treatment and redrying on the bending properties of southern pine. Forest Products Journal. 35(10): 62-68.

Winandy, J. E. 1988. Effect of treatment and redrying on mechanical properties of wood. Wood protection techniques and the use of treated wood in construction: Proceedings 47358; 1987 October 28-30; Memphis, TN. Madison, WI: Forest Products Research Society: 54-62.

Wood handbook- Wood as an Engineering Material. 1999. Gen. Tech. Rep. – 113. Forest Products Laboratory, USDA Forest Service, Madison, Wisconsin.

Yamamota, K., Motegi, S. and Inai, A. 1999. Comparitive study on the leaching of wood preservatives between natural exposure and accelerating laboratory conditions. Do No. IRG/99-30203. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Zhang, J. and D. P. Kamdem. 1999. Interaction of copper amine complexes with wood: Influence of copper source, amine ligands and amine to copper molar ratio on copper retention and leaching. Do No. IRG/99-50134. Inter. Res. Group on Wood Preservation, IRG, Stockholm, Sweeden.

Zhang, J. and D. P. Kamdem. 2000. FTIR Characterization of copper ethanolamine – wood. Wood interaction for wood preservation. Holzforschung. 54: 119-122.

Zhang, J. and D. P. Kamdem. 2000. Electron Paramagnetic Resonance Spectroscopic study of Copper amine treated Southern pine in Wood Preservation. Holzforschung. 54: 343-348.

Zhang, J. and Kamdem, D. P. 2000. X- Ray Diffraction as an Analytical Method in Wood. Holzforzhung. 54 (1): 27-32.