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New Microwave Applicator for Timber Surface Modification (Modelling, Design and Tests)

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Abstract **To meet timber protection requirements the wood surface area must be impregnated with preservative solution to a depth up to 20 mm. To provide effective solution penetration in the timber it is possible to increase the surface permeability by microwave wood modification. With this aim a special microwave applicator, PC-1 at frequency 2.45 GHz, was designed, built and tested. Experiments showed that the PC-1 applicator concentrates MW energy mainly in timber surface areas. The tests verified the suitability of the applicator for practical use. The PC-1 applicator is recommended for commercial MW log treatment and can be used for surface heating different dielectric materials.**

Keywords - wood modification, microwave modification, microwave applicator, wood permeability

I. INTRODUCTION

The use of the round and sawn timber in Australia is limited by low durability. Poles, posts and lumber must be impregnated with preservatives to have high durability. Many wood species are practically impermeable and preservative solutions do not penetrate this timber. MW modification of wood structure increases the wood permeability and opens new opportunities for increasing timber durability by impregnation with preservatives [1].

Untreated timber is readily attacked by fungi and insects. It will decay very quickly when in contact with the ground or in moist conditions. Many timber species must therefore be preservative treated according to Australian Standard 1604.1 (2002) [2] prior to being used in such applications. For use in an outdoor environment with direct ground or water contact (retaining walls, piling, housing supports and building poles (hazard class H5), preservative is required to penetrate not less than 20 mm from the surface of the timber.

MW applicators used for timber modification treat all timber cross section [3, 4] and provide full cross sections preservative penetration. It results in high chemical consumption, high energy consumption and some timber strength reduction. A surface timber treatment reduces these shortcomings. Powerful industrial MW generators are working at frequencies 2.45 and 0.922 GHz. Frequency 2.45 GHz is more suitable for surface modification because MW penetration is much lower compared to 0.922 GHz.

The way to remedy this problem is to develop a special MW applicator at frequency 2.45GHz which can provide energy concentration mainly in shell areas of the timber.

The research and development objectives include:

- design and modelling of the applicator for timber shell area modification,
- computer optimization of the applicator parameters and manufacturing of the applicator,
- experimental study of the MW interaction with logs in the applicator,
- study of the effect of MW modification on preservative distribution and uptake in logs and determination of the rational process parameters of modification,
- determination of the effect of MW modification on the peeler core strength properties,
- recommendations for the applicator commercial use.

II. APPLICATOR DESIGN AND SIMULATION

The MW applicator working at frequency 2.45 GHz must provide modification of shell areas of the log or sawn timber on the depth up to 20 mm in the timber range sizes from 90x90 to 140 x 140 mm. To perform this task a waveguide radiator with open narrow wall was chosen (Fig. 1).

Rational size of the cut depth "d" in the wide waveguide wall was chosen by computer modelling of the energy distribution in the timber by using program CST Microwave Studio. Size "d" varied in the range from 1 mm to 60 mm and depth of the log position in radiator was changed in the range from 1 mm to 40 mm. Fig. 2 demonstrates energy distribution in the log at parameter "d"= 10 mm and depth of the log position in the radiator 10 mm.

After analysis of the simulation results, a 25 mm depth of the cut in the wide waveguide wall of the radiator was chosen for the experimental applicator PC-1. Fig. 3 illustrates predicted modified zones in the log. PC-1 applicator consists of two radiators and provides modification of top and bottom areas. Two PC-1 applicators connected with two generators can provide modification of the shell zone of the log for preservative penetration according requirements

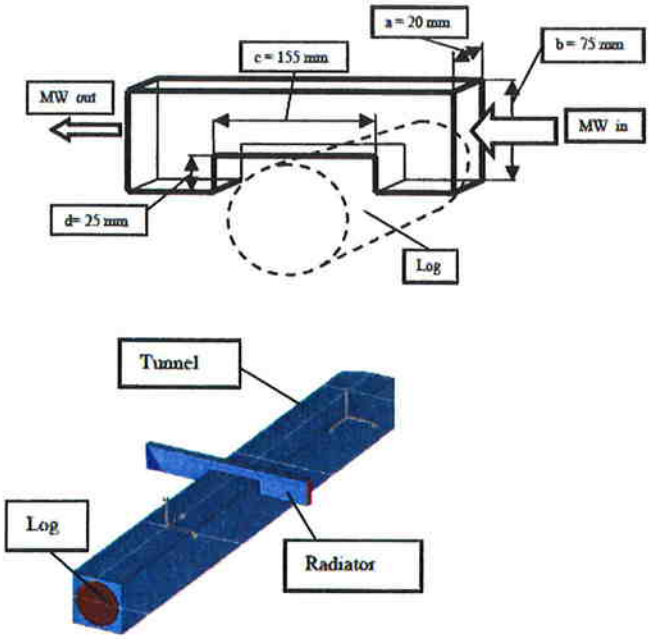

Figure 1. Radiating part of the applicator and its position on the tunnel. a – size of narrow waveguide wall, b – size of wide waveguide wall, c – tunnel size (length of the open part of the narrow wall), d - depth of the cut in the wide waveguide wall.

III. EXPERIMENTAL METHODS

For determination of the practical application of the PC-1 applicator for log shell zone modification the following experimental study was carried out. The study of temperature distribution in the timber and preservative distribution after modification were used for estimating the PC-1 applicator effectiveness.

A. *Material*

Radiata pine (*Pinus radiata*) peeler cores (cylindrical logs), heartwood radiata pine sleepers and hardwood eucalyptus sleepers (species Karri *(Eucalyptus deviri-coler)* and Jarrah (*Eucalyptus marginata*) were used for experiments. Peeler core dimension varied between 126 to130 mm in diameter

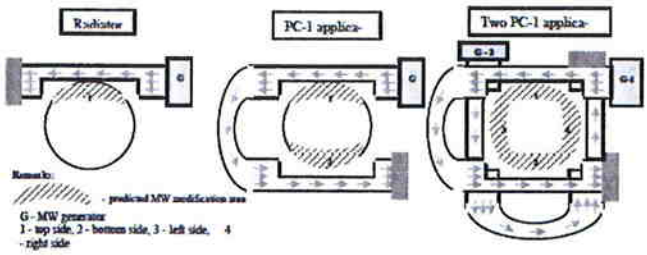

Figure 3. Predicted MW modified zones in the log for one and two PC-1 applicators

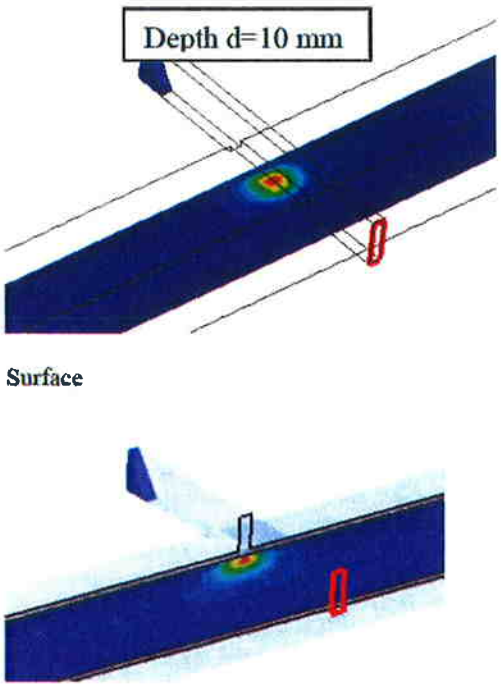

Figure 2. Energy distribution on log surface and inside the log at a depth of the cut in the wide waveguide wall 10 mm and a depth of the log position in the radiator 10 mm.

and 2560 mm in length. Radiata pine sleepers had dimensions of 125 mm x 130 mm x 2200 mm. Moisture content and oven dry density of radiata pine timber ranged between 26 – 31% and 367 – 406 kg/m^3.

Green hardwood sleepers had a cross section size of 125x130 mm, length 2100 mm and moisture contents 60-77 % for Karri and 27-41% for Jarrah. The oven dry density of the hardwood timber was 800 – 870 kg/m^3 for Karri and 730-880 kg/m^3 for Jarrah.

B. *Experimental Installation*

Two microwave applicators PC -1 were set up in a 60 kW MW experimental plant with two MW generators 30 kW each at frequency of 2.45 GHz. It has a tunnel with a cross section of 155 x 155 mm. The logs were conveyed through the tunnel using feeding rollers with different speeds.

C. *Temperature Measurements*

Temperature distribution in timber was measured to estimate the energy distribution provided by the applicator. During experiments, timber is held rigidly in the applicator and can be transported through the applicator at controllable speeds. Energy distribution within the timber was determined by measuring the temperature at different points across the timber cross section and along the log by thermocouples after MW heating the wood up to 80-100 °C.

MW power applied to the logs ranged from 17 to 36 kW measured by power meters during timber processing. MW energy applied to the logs ranged from 55 to 90 kWh/m^3. Vapours and water released from the wood

during the modification were removed from the applicator by using a high speed 90-110°C air flow directed through a tunnel.

D. *Preservative Treatment*

After MW processing the timber was impregnated in a pressure vessel with a water based solution of *Copper Chrome Arsenic (CCA)*. MW processing variables manipulated for MW log processing included MW power, MW energy consumption and speed of the timber in the applicator. Electric field strength vector E orientation was parallel to the wood grain. Wood modification quality was determined by examining preservative distribution in the cross section, preservative uptake, check distribution in cross section and along the length, log shape changes and strength properties.

Peeler core bending strength and stiffness was tested by the Salisbury Research Centre D.P.I., Queensland, Australia according to the methods specified in Australian Standard AS/NZS 4063 (1992) [5].

IV. Result and Discussion

A. *Temperature Distribution*

After one side of MW treatment, the highest temperatures were recorded on the surfaces of the peeler core. There was then, a gradual decrease in temperature with depth in the peeler core. The top sample zone attains the highest temperature (>80°C) up to the depth about 10 – 30 mm. Outside this zone, the temperature gradually dissipates with depth in the timber. The length of MW distribution zone along the sample was 75-90 mm on both sides from the radiator centre.

After microwave heating the highest temperature was recorded on the surfaces of the peeler cores up to a depth of 10 – 35 mm. This shows that applicator PC-1 effectively distributes the microwave energy mainly to the surface of the timber.

Fig. 4 illustrates temperature distribution in radiata pine sleepers following energy application from the top radiator. The highest temperatures are recorded on the surfaces of the wood. This means that timber surface areas can be modified to provide preservative penetration to any required depth.

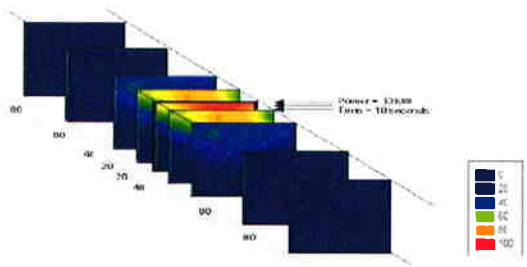

Figure 4. Temperature distribution in the radiata pine sleepers (125x130 mm) following single top energy application from the PC-1 applicator (MW power 10 kW applied for 10 seconds).

Results of temperature measurements in the sleeper (Fig. 4) show energy release mainly in the shell area with a maximum energy concentration near the radiator centre.

PC-1 applicator can provide MW modification of the shell areas of the round logs and sawn timber. One PC-1 applicator treats a log from two sides. Two PC-1 applicators can treat timber from 4 sides to provide total shell area modification. Compared to conventional applicators which heat full log cross section, the PC-1 applicator allows modification of the shell zone and reduces energy consumption significantly because the energy release takes place mainly in the shell. To ensure a more uniform treatment of the log, 3 or 4 PC-1 applicators can be used in one MW plant.

B. *Preservative Distribution*

Copper spot testing shows that after MW modification, preservative penetrated the peeler cores. Preservative impregnation of the modified samples verifies solution penetration of heartwood via voids while in non-modified samples, preservative did not penetrate. Fig. 5 demonstrates preservative penetration to Karri timber samples with moisture content 70% after MW modification and impregnation of the sample top. The use PC-1 applicator for hardwood sleepers can reduce MW energy consumption up to 20%.

Figure 5. Karri timber sample with moisture content 70% after MW modification of the sample top and impregnation.

Following microwave modification, preservative uptake was increased significantly. Modified peeler core preservative uptake ranged from 94-314 L/m^3, while the uptake of non-microwave heated peeler cores was around 35 L/m^3. Microwave surface treatment enhanced preservative uptake 3-9 times than that of the uptake achieved in control samples.

MW energy consumption for peeler core full cross section preservative treatment at frequency 0.922 GHz is 100-110 kWh/m^3 [3]. The PC-1 applicator provides significant energy savings and uses only 65-75 kWh/m^3.

MW modification does not produce significant changes in the size and shape of the logs. Strength tests of 30 MW treated peeler cores with applied MW energy 111 kWh/m^3 showed the average log modulus

of elasticity at MC= 21.7% was 6.6 GPa with a variation coefficient of 27.2%. The modulus of rupture was 31.9 MPa with a variation coefficient of 23.5%. The radiata pine peeler cores can be rated grade F7 according to Australian Standard AS1720 (1997)[6].

V. CONCLUSIONS

Special MW applicator PC-1 at frequency 2.45 GHz was designed to modify timber surface areas for increased wood permeability. Experiments showed that the PC-1 applicator concentrates MW energy mainly in timber surface areas. A study of energy distribution in timber following MW irradiation showed that an applicator provides surface conditioning of the round logs and sawn timber to a depth of 10–35 mm. A significant improvement in wood permeability was achieved and verified by preservative impregnation of the microwave modified samples. Microwave surface treatment enhanced preservative uptake 3-9 times than that of the uptake achieved in control samples.

One PC-1 applicator treats a log from two sides, two PC-1 applicators can treat timber from 4 sides to provide all shell area modification. Compared to conventional applicators which heat the full log cross section, the PC-1 applicator allows modification of shell zones and reduces energy consumption significantly. To achieve more uniform treatment of logs, 3 or 4 PC-1 applicators can be used in one MW plant.

The tests verified the suitability of the applicator for practical use. PC-1 applicator is recommended for commercial MW log treatment and can be used for surface heating different dielectric materials.

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