USING COMPUTER SIMULATION TO STUDY THE DYNAMICS OF MOISTURE DISTRIBUTION IN WOOD

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Abstract: The mechanism of moisture movement through wood has been extensively studied because of its fundamental importance in understanding the behaviour of wood during processing and when it is in service. However, most studies were done using conventional experimental methods which sometimes can be tedious, time consuming and destructive where materials are wasted. Computer simulated studies allow shorter lead time and also reduced greatly destructive analysis of test specimen. Theoretically, it is possible to trace the movement of moisture in timbers through heat or mass transfer analysis or both. In this study, the dynamic profiles of moisture movement in a tree trunk were determined at a series of tree heights using the finite element method (FEM) of steady-state heat transfer analysis. An *Acacia mangium* tree was selected from an *Acacia mangium* plantation of 6 – 15 years of age in Serdang, Malaysia to study the moisture distribution and height relationship. It was deduced from the results that the moisture movement at the butt-end of the tree was higher than the moisture movement at the top of the tree. The resulting numerical solutions (FEM) matched well with experimental results. It can be concluded that computer simulation can be an excellent tool for future lumber drying research, such as mapping induced drying stresses to analyse checking and warping in kiln dried timbers.

Keywords: Moisture distribution, Finite element method, Dynamic moisture profile

INTRODUCTION

Acacia mangium is a fast growing species attaining 15m height and 40cm DBH in 3 years. They have attained 23m tall in 9 years. The wood dries fairly rapidly and without developing serious defects. The timber responds satisfactorily to preservative treatment [1].

Wood is hygroscopic in nature and will gain or loss moisture with changes in atmospheric humidity. When moisture evaporates from the surface of a piece of wet wood the moisture concentration in the outer layers is lowered and moisture begins to move from the wetter interior to the drier surface.

If the evaporation from the surface occurs at a faster rate, then the moisture from the interior zones flows to these surfaces. Thus, the moisture gradient within the wood becomes progressively steeper. As the outer layers dry below the fibre saturation point their tendency to shrink is resisted by the wetter interior so that a state of stress develops, with the outer layer in tension and the inner zones in compression. If the stresses become too severe the outer layers may rupture, i.e., surface checking may occur, or they may become stretched beyond the elastic limit without breaking and the wood is then said to be casehardening.

Understanding of the flow characteristics of moisture in wood will help in the efficient drying and design of wood-based products. Computer simulation had been used in studying heat and mass transfer in wood [3,5]. Analysis on heat and mass transfer and product performance by computer simulation prior to product processing and manufacturing will reduce waste of raw material contributed by destructive product tests. This study described a non-destructive method for measuring moisture content distribution in *Acacia mangium* using computer simulation. The computer analysis can produce results faster, simultaneously and effectively compared to experimental analysis. It was the objective of this study to determine the movement of moisture in the stem of plantation – grown *Acacia mangium* by computer simulation.

MATERIALS AND METHODS

Preparation of Specimens

A tree was selected from an *Acacia mangium* plantation of 6 – 15 years of age in Serdang, Malaysia. to study the relationship between moisture distribution and tree trunk height. The healthy tree was randomly selected and felled. The selection was done based on criteria such as bole straightness, absence of excessive defect and good cylindrical form. The selected tree was a 7-year-old *Acacia mangium* with 16 m height and 19.8 cm diameter, four different sampling heights were chosen; breast height (DBH), 15%, 35% and 65% of the total tree height.

Experimental Analysis

At each height, one disc was removed. Two specimen blocks measuring 1 X 1 X 4 inches as described in ASTM standard D 143 (1983) were cut from strips and labelled. The moisture contents of the blocks were determined by oven-dry method. The green weight was obtained by weighing the blocks after soaking them in the water.

Finite Element Method (FEM) of Analysis

The FEM of analysis examined the dynamic changes of moisture transfer as the wood dries. The wood was divided into small elements with each element having different values of moisture conductivity. Development of the model required the following components:

1. A mathematical distribution of moisture content over wood cross sections given any combination of average wood moisture content (MC) and external equilibrium moisture content (EMC) conditions.
2. A general three-dimensional finite element program capable of solving non-linear problems and a model of a small sample with enough elements to adequately reflect MC variation.

First, all the gathered input data such as moisture content and tree height of the modelled wood disc were entered into the material properties matrix. The standard unit system chosen in this study was the International Standard (SI) System.

Then the model load, which type and magnitude is closest to simulating the effects of the actual loading condition, was defined and entered into the force matrix. In moisture movement analysis such as in this study, the loads were mass moisture diffusion and mass moisture variation. All loads were applied directly to the entire body of the studied model. The direction of the loads was defined in the Cartesian coordinate system. Next, restraints or boundary conditions were applied directly to the geometry of the simulation model.

Automatically with the help of the FEA pre-processor a mesh of quadratic tetrahedral elements was created on the solid simulation model. Thin-walled models were meshed with triangular shell elements. The meshed models presented recommended default element sizes based on the models' geometry dimensions. The mesh was characterised by a number of features and the properties of the material was assigned to it. The inputs to the structural and mass moisture movement analysis included material property information such as thermal conductivity, specific heat and moisture content of the wood. Consequently, when the input phase of analysis was completed, the FEA solver was used to analyse the created model.

Verification of FEA Results

The results from the experiment were compared to those from the finite element method of analysis of mass transfer to determine if there were any differences or similarities in the trends. The dynamics of moisture distribution in *Acacia mangium* was then concluded based on both the thermal flux profile from the FEM of mass transfer analysis and moisture profile from the experiment.

RESULTS AND DISCUSSIONS

The results obtained from moisture determination experiment exhibited the increment of moisture content with decreased in tree height. The different moisture movements at different tree heights were driven by four major causes which were moisture content, diffusion coefficient, vessel diameter and the presence of spiral and interlocked grain.

Table 1: The moisture content of *Acacia mangium* based on four sampling height

Cross section relative to tree height	Diameter, cm	Moisture content, %
Breast Height	23.1	88.24
15%	19.8	67.49
35%	16.8	59.95
65%	7.3	54.19

The results obtained from the mass moisture distribution experiment and the FEA analysis showed that the moisture decreased from the butt-end to the top end of the *Acacia mangium* tree. In the experiment, the differential of moisture content (Table 1) along the tree height indicated the moisture movement in the *Acacia mangium*. Whereas in the FEA analysis, the differential heat transfer inferred the moisture movement in the *Acacia mangium*.

The ease of moisture movement should increase with increase in moisture content [7]. At low MCs, water molecules are believed to be tightly bound to localised sorption sites in the wood, whereas at higher moisture content a greater fraction of them are bound less tightly and therefore are more mobile. The rate of movement is directly proportional to the number of molecules with energy in excess of the bonding energy. Therefore, as observed in this study, the moisture movement decreased at the 65% of the total tree height compared to the breast height of the tree.

Since mass transfer is analogous to heat transfer, the FEM of analysis exhibited the profile of moisture transfer in wood at different tree height by using the thermal flux profile of the heat transfer. The increased moisture contents will increase the heat transfer [7]. In this study, the values of the thermal flux obtained were higher at the butt-end of the tree compared to the top end of the tree. Therefore, it can be deduced from the results of this study that the moisture content is higher at the butt-end and lower at the top of the tree.

The results obtained in this heat transfer analysis successfully exhibited the contour of thermal flux at different sampling height. Thermal flux is a product of diffusion coefficient and thermal gradient. It was observed that sample disc located at the breast height of the tree exhibited the highest thermal flux. While the sample located at 65% of the total tree height exhibited the lowest thermal flux. Therefore, it can be concluded that diffusion coefficient decreases from the bottom end to the top end of the tree height.

Hart [4] assumed that all moisture movement in wood, even above the fibre saturation point, is driven by diffusion, while Bramhall [2] considered the water vapour-pressure gradient as the driving force. The simulation results obtained matched well with experimental results which indicated moisture movement decreasing based on the tree height (Figures 1 and 2).

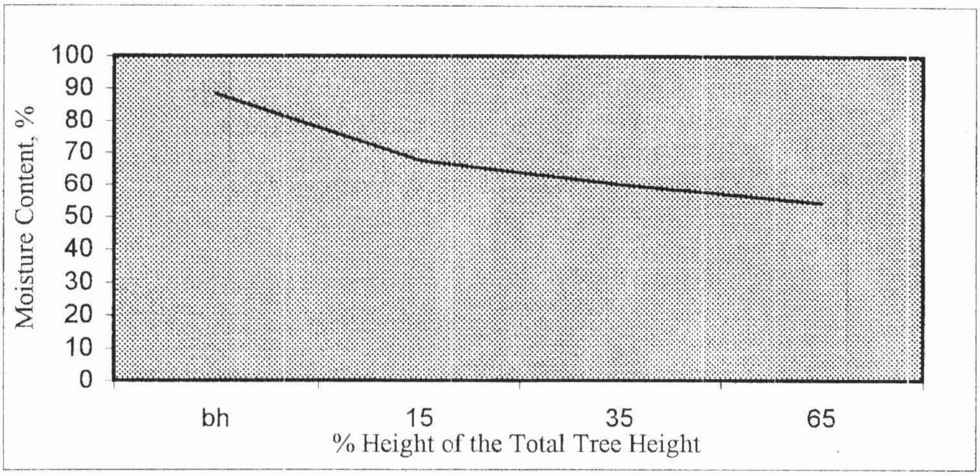

Figure 1: The trend of the moisture movement based on tree height by using experimental results

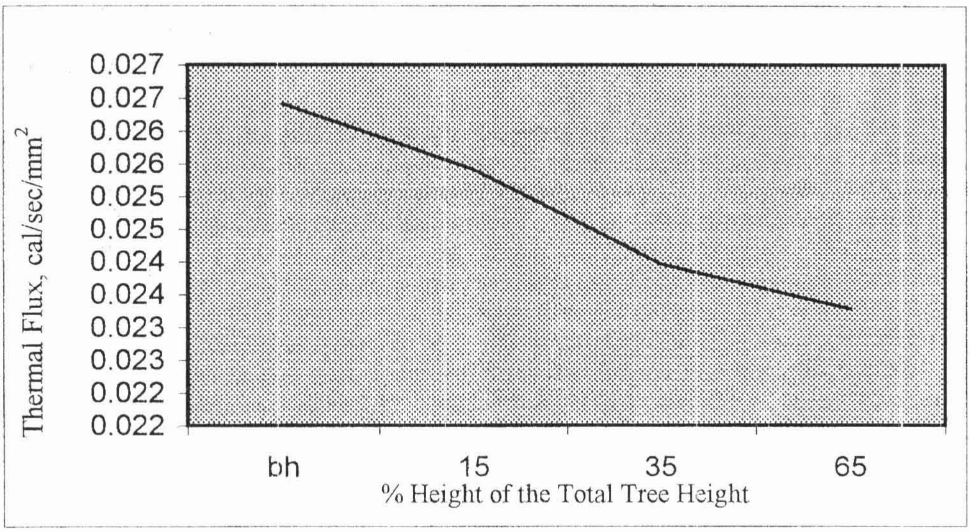

Figure 2: The trend of moisture movement based on tree height produced from computer simulation results

Acacia mangium wood is diffuse-porous with mostly solitary vessels. Therefore, the vessel diameter is a strong function of moisture movement. The vessel diameter decrease with increasing tree height [6]. The decrease vessel diameter complicated the water movement [8]. Therefore smaller vessels diameters at the upper tree height decreased the moisture movement as indicated in this study.

Also, the presence of spiral grain that often to a lesser or greater extent also caused moisture variation along the tree height. Left-turning spiral grain can change over the years into right-turning grain. The change happens regularly and interlocked grain occurred. This physiological significance of the complicated patterns of water movement is obvious. The spiral and interlocked grain change over the years and become greater at the upper tree height, therefore moisture movement at the upper tree is difficult and moisture content tends to be low.

Moisture changes within a tree can be due to the daily and annual moisture variations in the surrounding air. The moisture content variation in timber in normal environmental conditions can be predicted. The variation may be due to the genetic differences that are inherited in the individual tree.

In addition to the genetically controlled effects, differences were also due to the site micro-environment of the growing trees. The mean temperature and mean annual rainfall may also have some effect on growth and finally to the amount of wood material produced by the tree.

CONCLUSION

This study was designed to investigate how well the moisture distribution can be simulated by the computer simulation. The comparison between experimental results and FEA results showed similar trend of moisture movement along the tree height. Therefore computer simulation is an excellent tool in demonstrating the moisture movement in wood.

The computer simulation showed how diffusion coefficient varied with tree height. The FEA results showed the top of the tree had lower diffusion coefficient compared to the bottom of the tree. Since moisture movement in *Acacia mangium* is driven by diffusion, therefore moisture movement is faster at the bottom of the tree compared to the top of the tree.

Three major advantages of using computer simulation are: the sensitivity of the model's response to the changes of moisture movement can be easily determined; the solution can be generalised among different tree height; and the relationships between *Acacia mangium*, moisture and thermal can be analysed. Therefore, wide and increasing use of computer by the researchers can facilitate practical application of theoretical consideration especially in wood drying.

The advantages of computer simulation in this study can be further utilised to analyse the stress development during wood drying. The stress development in *Acacia mangium* during drying can be determined using FEM with the results gathered from the heat transfer analysis. The results obtained will be useful for improving the drying process and help the researchers to minimise or eliminate the stress development during wood drying.

The mass moisture movement in *Acacia mangium* tree studied based on the *Acacia mangium* trunk height. The results obtained only represented the mass moisture movement caused by the wood physical properties such as vessel diameter, orientation of grain and moisture content. However, these results can be incorporate into future studies to determine the moisture movement in *Acacia mangium* tree with consideration on the transportation of moisture forced by the biochemical and metabolism processes such as transpiration, respiration and photosynthesis.

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