J. Fiz. UTM. Vol. 3. (2008) 58-67

A STUDY OF MOISTURE DISTRIBUTION IN MALAYSIAN WOOD BY NEUTRON RADIOGRAPHY

Wan Muhamad Saridan Wan Hassan*, Yeong Wai Woon*, Azali Muhammad#, Mohd Rawi Abdullah#, and Rafhayudi Jamro#

*Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Darul Takzim
#Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor Darul Ehsan

ABSTRACT

A study on moisture distribution in several types of Malaysian wood is presented, based on the transmission of various wood samples by neutron beam via neutron radiography technique. The aim of the study was to investigate the water uptake behaviour, and drying process in different species of wood. The experimental set-up, the detector system used and the evaluation procedure are described. Neutron radiographic images that describe the moisture distribution in the wood samples have been produced. Qualitative information obtained from the images provides a general understanding of the behaviour of wood during its interaction with water under different conditions. Results obtained indicate the potential for further use of this method in studying several moisture-related practical problems in wood manufacturing industry.

Keywords: Neutron radiography, Malaysian wood, moisture distribution

INTRODUCTION

Wood is one of the oldest and best-known structural materials. Today, it still plays an important role in the building and furniture manufacturing industries. The properties of wood are heavily influenced by its moisture content. Majority of the disturbing and destroying events like swelling, attacks by fungus and appearance of cracks takes place due to the changing in moisture content of wood [1, 2].

A study was conducted to investigate the moisture distribution, water uptake behavior, and drying process in a number of Malaysian wood samples by neutron radiography. Water can be detected very efficiently by neutron due to its high attenuation coefficient with water. Thus, it is possible to describe the distribution of the chemically bonded hydrogen and the changes of moisture in wood by using the neutron radiography method.

METHOD AND MATERIALS

The neutron radiography work was performed at the thermal neutron radiography facility at the Puspati Triga Reactor, Malaysian Nuclear Agency. The reactor is a swimming pool type light water research reactor. The fuel elements are zirconium hydride alloys embedded with enriched uranium and clad with stainless steel. A mixture of americium and beryllium is acts as the neutron source. Four control rods are used to control the fission reaction inside the core. The reactor uses light water as moderator and high purity graphite as reflector. With an operating power of 1 MW, the thermal neutron flux produced is 1.2×10^{12} neutrons cm^{-2} s^{-1} at the edge of the core [3].

The neutron radiographic facility is situated at tangential beam port. The collimator is a step divergent type that splits into three cylindrical parts. The front and back parts are fabricated from rolled plates and welded to the aluminium-casted shoulder. There is an annular disc at the end of the front cylinder. The thermal neutron flux is 5×10^5 neutrons $cm^{-2}\ s^{-1}$ at a power of 750 kW. The value can be increased up to 1×10^6 neutrons $cm^{-2}\ s^{-1}$ depending on the arrangement of the nuclear reactor fuel. Exposure of 150 kW-hours gives a film density of 2.0 and unsharpness of (99 ± 14) μm [3].

Investigation of the Water Uptake by Different Kinds of Wood Samples

The first part of the study is the investigation of the moistening process on seven types of Malaysian wood namely *Jelutong*, *Kempas*, *Keruing*, *Meranti (light red), Nyatoh, Sepetir, and Rubber wood*. Specimen blocks of the wood of size 40 mm x 15 mm x 180 mm each were set into a shallow water bath, so that the specimens were wet-ted from below. They are wetted for different times namely 180, 360 and 480 minutes to study the water uptake. Specimens were then stuck on the back of film cassettes by using aluminium tape. Next, film cassette along with the specimens was placed at a cassette holder made from aluminium. The cassette holder (along with the film cassette and wood specimens) was placed on a trolley inside the irradiation room. The cassette holder was placed so that the direction of the beam of radiation was as perpendicular as possible to the plane of the film. A long tong was used to push the trolley to a location in front of the beam lead aperture. Then, the door of irradiation room was closed. Before each exposure, the staff at reactor control unit must be informed via phone. The lead shutter was opened by pulling a long iron rod. Once the lead shutter was opened, the exposure time begins. The specimens were exposed for 18 minutes.

The exposed films were removed from film cassette and then kept into a black plastic bag for film development. The radiographs were digitized by DiagnosticPro Plus film digitizer with 8 bit gray value and resolution of 300 dpi. The images of the specimens on the digitized image were cropped. The cropped images were inverted, and median filtering was applied. Image subtraction from dry specimen was performed followed by histogram stretch, contrast and brightness adjustment. Figure 1 summarizes the method undertaken.

Studies about Drying Behavior of Wood

The second part of the study is the investigation of drying process of woods. Three wooden samples were studied, i.e. *Jelutong*, *Keruing* and *Rubber wood*. The size of each sample is 45 mm x 45 mm x 25 mm. The dry weights of wood were measured by using electronic balance. Later, all the wood samples were saturated by immersing it under water for 3 days at room temperature, 20 °C. The total increase in mass for each wood specimen was measured and recorded. For each kind of wood species, two wood specimens were prepared. The first, with totally free sample which can dry in all direction by evaporation and the other with isolated surface (covered by aluminium plate) at one of the large surface, which is in the direction of the incidence beam. The isolated surface is in the direction of the wood fibres. After being immersed in water for three days, the wood specimens were dried in air at room temperature of 20 °C. The samples were then neutron radiographed. The radiographs obtained represent the transmission images through the 25 mm thick samples after drying time intervals of 4, 24, 48 and 53 hours. The weight of each sample was measured in parallel. The radiographs obtained were si-milarly analysed as in section 2.1. Figure 2 summarizes the method undertaken for this work.

RESULTS AND DISCUSSION

Water Uptake by Different Kinds of Wood Samples

Figure 3 shows the increase of the sample weight during the wetting procedure for all the seven types of wood samples. The increase in weight of sample represents the accumulated water in the samples after 180 min, 360 min and 480 minutes of wetting from below.

Radiographs of water uptake within 8 hours for all the seven types of wooden samples have been obtained. Figure 4 is the visualization of the moisture movement inside a *Jelutong* sample applied from below during its wetting time for eight hours. Measurements were made after 0, 180, 360 and 480 minutes. The images were produced by differences to the dry state image. Area with water will have higher value of optical density (darker).

Figure 5 shows the optical density (OD) curves for various wetting time intervals for *Jelutong*. The curves represent the OD at the centre vertical axes of the image. Curves were fitted by using Matlab 6.5 spline fitting.

A qualitative impression about the moisture distribution inside a *Jelutong* sample over a period of some hours was provided by using neutron radiography. *Jelutong* is the wood species with the largest quantity of water uptake. The outer boundaries of the ima-ges contain more water, implying that an important part of the moisture remains at the surface. From the OD curves, it was found that water has moved upward about 3.5 cm after three hours of wetting time. The height of water uptake is 4 cm after six hours wetting time, and 6 cm after eight hours of wetting.

Wood is an organic material that originally contains some water in the dry composition and therefore a high hydrogen background. Only by removing the original dry state in the individual time steps, the small additional amount of water can be made visible.

The rate of water absorption differs for each species of wood. Observation from the radiographs produced (Figure 6) indicates the following results, in ascending order of rate of water absorbtion:

Keruing, *Kempas*, *Meranti* (*Light Red*), *Sepetir*, *Nyatoh*, *Getah*, *Jelutong*.

The denser the wood, the less water will be absorbed. The qualitative information from the images in different time steps of wetting is in good correlation with the quantitative data in Figure 3.

Observation from the neutron radiographs shows that water is mainly distributed close to the surface only for most of the samples.

The only exception is *Kempas*, which absorbed about 2 g of water, but did not show any water uptake from the images. This is due to high moisture content in the original dry wood, and thus very difficult to distinguish small additional amounts of water in the wood.

Drying Behaviour of Wood by Neutron Radiography

Figure 7 shows the measured reduction of water in the investigated wooden samples (*Jelutong*, *Keruing* and *Rubber wood*), for both insulated and uninsulated samples, by drying in air for 53 hours.

Series of radiographs of the three types of wood for both insulated and uninsulated samples, dried in air over 53 hours were obtained. Figure 8 shows the OD curves for the series of radiographs, represent the average OD value at the centre of image.

Figure 9 is the visualization of the drying process of two set of *Rubber wood* samples (insulated and uninsulated). Measurements were made after 0, 4, 24, 48, and 53 hours after the start of the drying process. Darker area in the images represent the area with lower concentration of water.

Image of uninsulated sample has a lower OD value at the starting point of drying process compared with the insulated sample. This is due to larger amount of water that has been absorbed when it was soaked into water for 3 days. After 72 hours, the amount of water that remains in the insulated sample is relatively larger, which implies that the insulated sample dried more slowly than the uninsulated sample. A small change in size during the drying process was found for both samples. The shrinking effect becomes visible by enhanced structures in the images and reduced outer size.

For the uninsulated case, the process of drying is homogenous, but the outer layer is drying a little faster than the inner part, illustrated by higher darkness in the boundaries of images.

For the insulated case, the drying process is slowed down due to insulation at the large lateral surface of the sample. Thus, images formed were brighter than the image of uninsulated sample.

The higher moisture content in wood, the lower OD of the radiograph produced, since more neutrons will be scattered by hydrogen.

All the free drying samples were dried homogeneously. However, the outer layer is drying a little faster than the inner part, thus produce a higher OD at the boundaries of each images.

For the insulated sample, the main transport way was insulated. Moisture can be delivered to air only through the other free surfaces. There is a wetness gradient inside the sample. This in turn caused the uneven water distribution inside the wood sample.

A comparison of the rate of drying among the different kinds of wood was unable to be made from the qualitative information of radiographs. This is due to the interaction of neutron on wood not only affected by its moisture content, but also affected by the initial chemical constituent of wood, which is varied for different kinds of wood.

Each wood sample has a considerable dimensional change during the process of wetting and drying when it was blown up by more than one third of its original weight during storage under water. The measurements on the images show that medium hardwood has a larger shrinkage compared with the light hardwood.

CONCLUSION

The ability and sensitivity of neutron radiography in investigating the moisture distribution in various kinds of Malaysian wood has been demonstrated. Neutron radiographic images of the moisture distribution within various wood samples during both the moistening and drying process were produced. Since there is some water in the dry wood composition, and therefore a relatively high hydrogen background, the small changes in amount of water can be made visible only by subtracting the images at different time steps with the image at original dry state. Qualitative information from the radiographic images gives a general understanding of the behaviour of wood during its interaction with moisture under different conditions. The value of neutron radiography to wood manufacturing industry has been demonstrated through the wealth of information it has provided through the studies on wood-moisture interactions under different conditions. The future work can be focused in quantifying the local amount of water in wood during wetting and drying process. Neutron radiography can be applied in studying some practical problems from wood manufacturing industry in the future.

REFERENCES

[1] Lehmann, E., Vontobel, P., Niemz, P., and Haller, P., "The Method of Neutron Radiography and its use for wood properties analysis" Proc. Int. Conf. Wood and Wood Fibre Composites, Stuttgart, 2000.
[2] Lehmann, E., Vontobel, P., and Niemz, P., "Investigation of Moisture Distribution in Wooden Structures by Neutron Radiography" PSI-Annual-Report 1999, Annex VI, p. 53.
[3] Rosly bin Jaafar, "The Development of Neutron Radiography and Its Potential Application in Malaysian Industries" in S. Fujine, K. Kanda, G. Matsumoto and J. Barton (eds), Neutron Radiography (3), Kluwer Academic Publishers, Dordrecht, 1990, pp. 171-178.

Specimens preparation

- Specimen blocks (40mm x 15mm x 180 mm) were set into a shallow water bath, where specimens were wetted from below.
- Three specimens were investigated simultaneously in one measurement.

↓

Radiographic Procedures

- Transmission images through the 15mm thick sample were produced after different wetting time steps (0, 180, 360 and 480 minutes).
- The integral water uptake is measured in parallel.

↓

Film Development

- Manual film processing in a dark room.

↓

Image Acquisition

- Radiographs were digitized by using DiagnosticPro Plus film digitizer.

↓

Image Post-processing

- Select region of interest in the images.
- Invert the image.
- Median filtering procedure.
- Image subtraction from the dry sample.
- Histogram stretch, contrast and brightness adjustment.

Figure 1. Experimental procedures in investigating the water uptake by different kinds of wood samples.

Specimens Preparation

- Specimen blocks (45mm x 45mm x 25 mm) were saturated by storing it under water for 3 days at room temperature.
- Total increase in weight was measured.
- Two series of tests for each type of wood:
  1. One with a sample that can dry in all directions.
  2. One with an aluminium layer as insulation at a large front surface, in the direction of the wood fibres.

↓

Radiographic Procedures

- Transmission images through the 25mm thickness were obtained after drying time intervals (0, 4^{th}, 24^{th}, 48^{th}, and 53^{rd} hours).
- The weight of each sample was measured in parallel.

↓

Film Development

- Manual film processing in a dark room.

↓

Image Acquisition

- Radiographs were scanned by using Cobra Scan film digitizer.

↓

Image Post-processing

- Select region of interest.
- Median filtering procedure.
- Histogram stretch and contrast adjustment.

Figure 2. Experimental procedures in the studies on drying behaviour of wood.

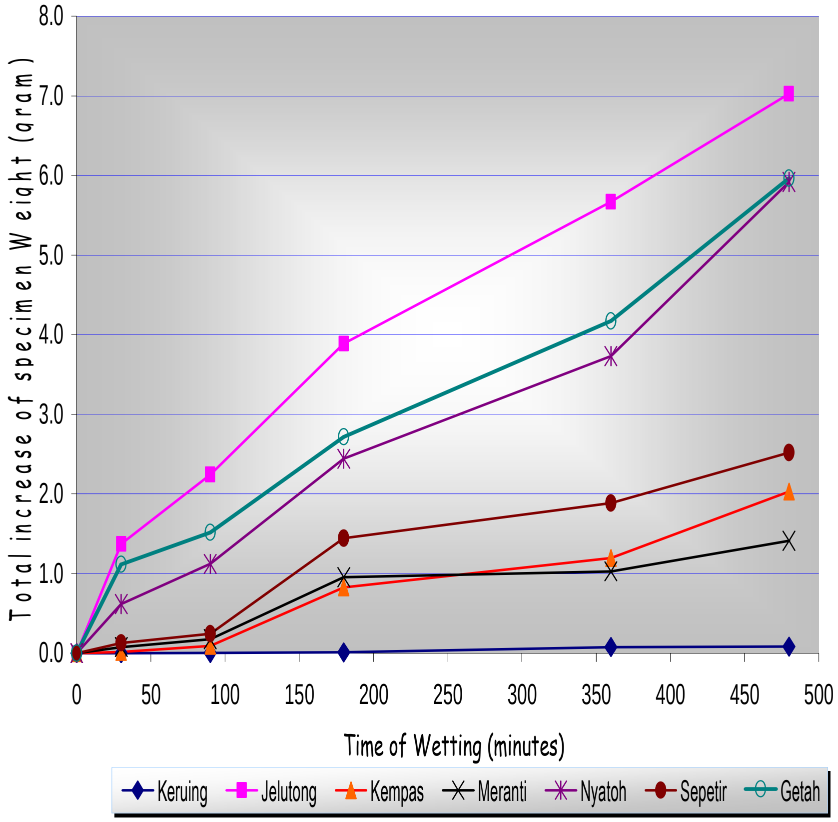
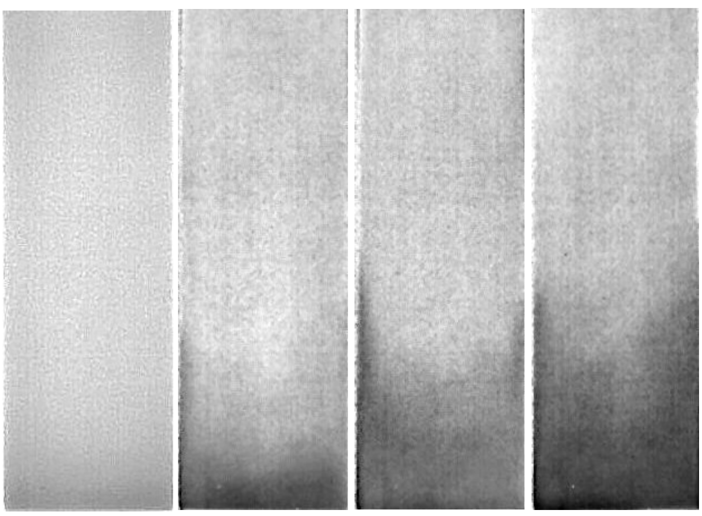


Figure 3. Increase of the weight of samples during the wetting procedure for different kinds of wood.



0 min 180 min 360 min 480 min

Figure 4. Visualization of the process of water uptake by a *Jelutong* sample during 8 hours of wetting.

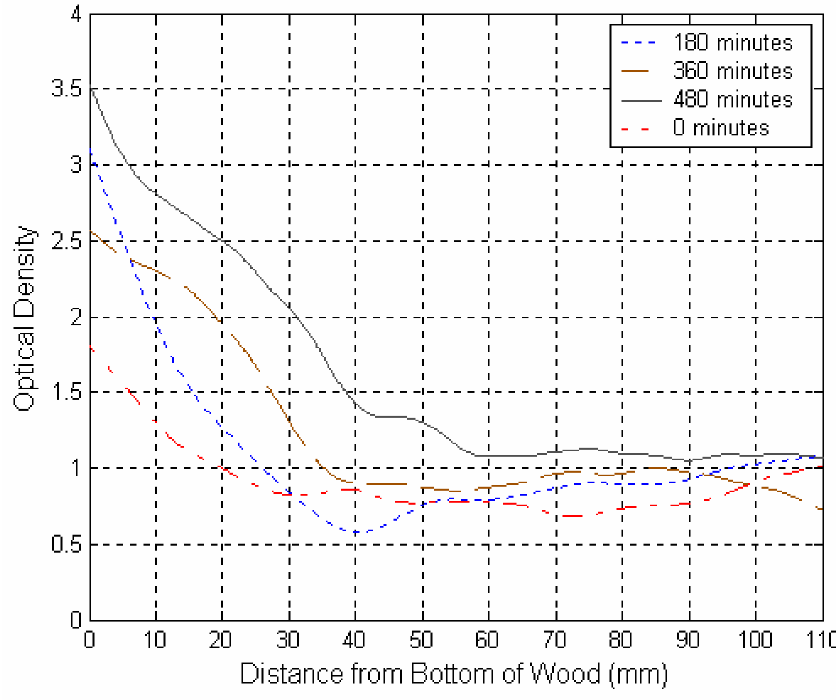


Figure 5. Optical density versus distance from bottom of wood of various wetting time intervals for *Jelutong*.

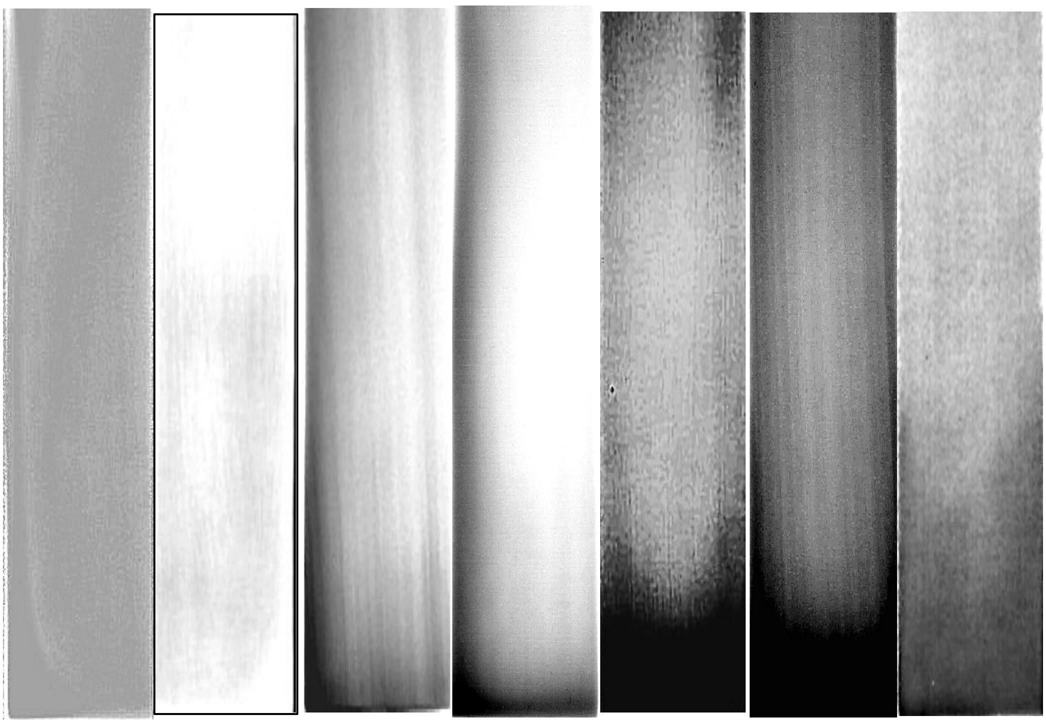


Figure 6. A comparison of the water uptake by seven kinds of wooden samples (from left to right: *Keruing*, *Kempas*, *Meranti* (*Light Red*), *Sepetir*, *Nyatoh*, *Getah*, *Jelutong*) after 8 hours of wetting.

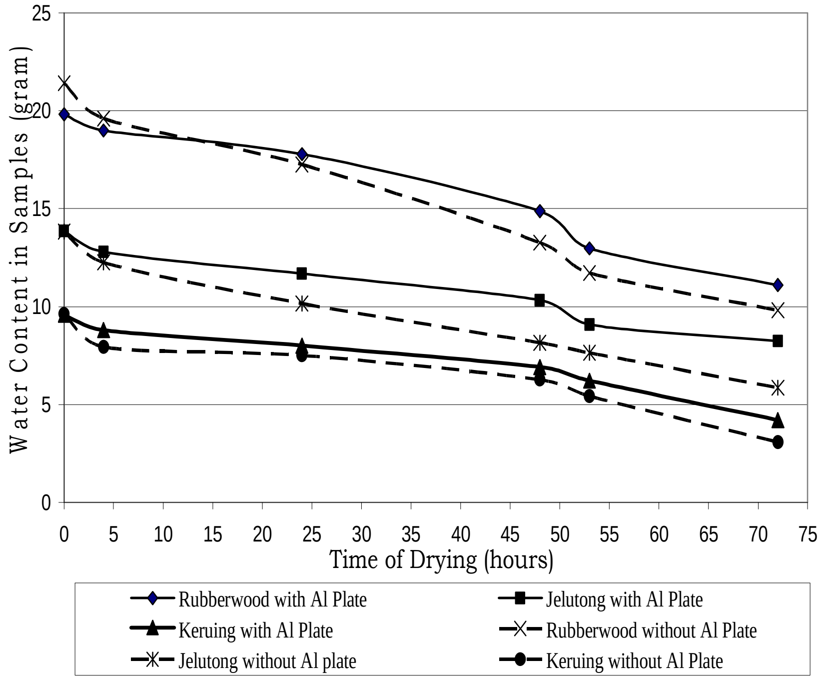


Figure 7. Reduction of water in the investigated wood specimens by drying in air, observed for 72 hours. (Water content = Total weight – Weight of dry specimen).

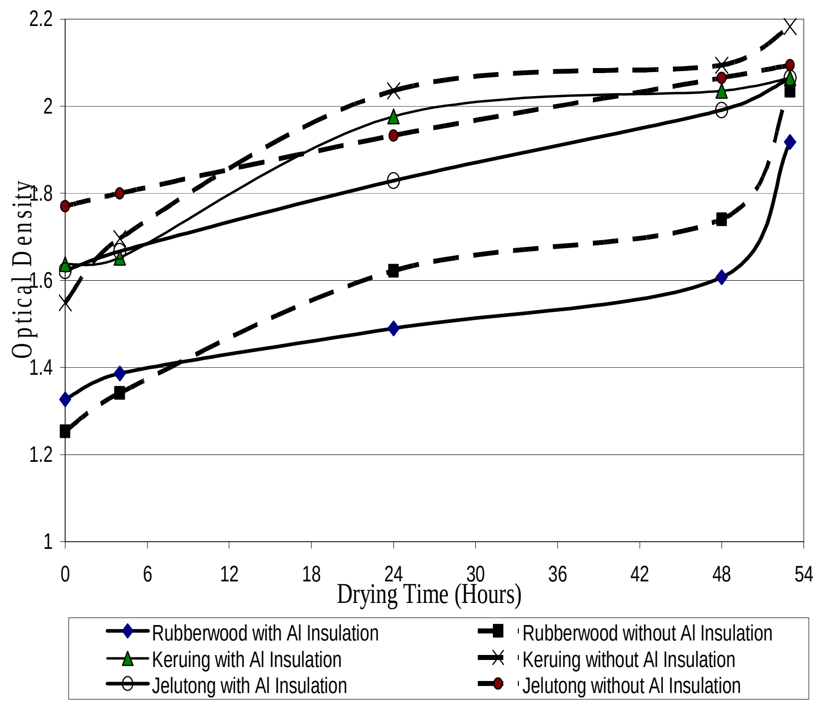
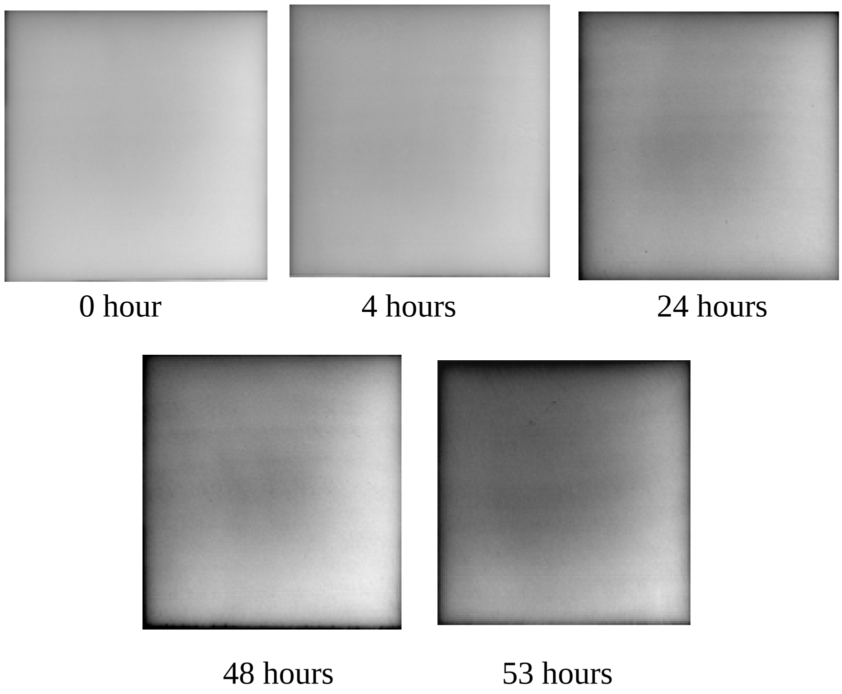


Figure 8. Relationship between optical density and drying time for both insulated and uninsulated samples of *Jelutong*, *Keruing* and *Rubber wood*.

Rubber wood sample without insulation



Rubber wood sample with insulation on one large surface

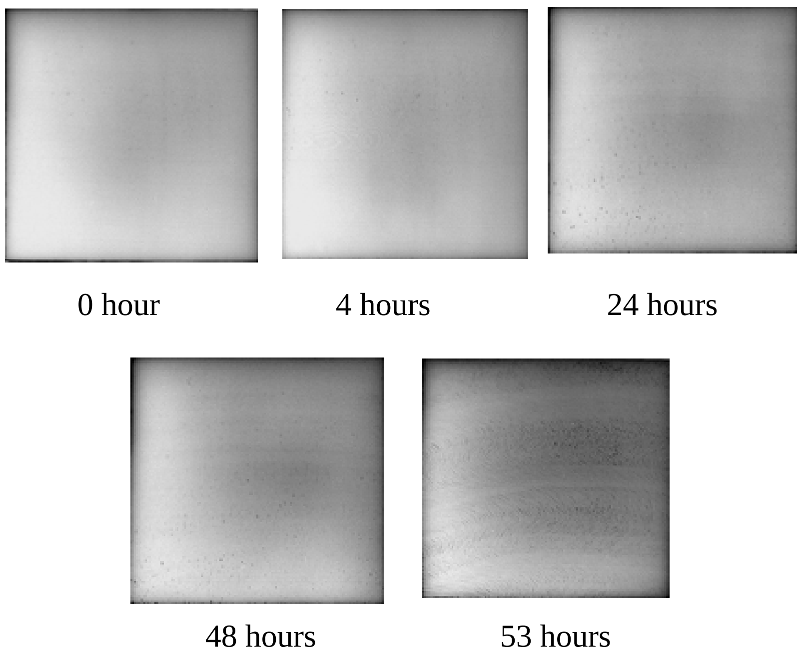


Figure 9. Observation of the drying process of two set of *Rubber wood* sampel (above: Uninsulated and below: insulated), dried in air for 53 hours.