Chapter 3

EXPERIMENT AND METHOD

3.1 Wood Samples

Rubberwood was chosen because it is a locally available, commercially important species. For this research, rubberwood lumbers were selected at Ruttapoom Parawood Factory in the Songkhla Province, Thailand, with dimensions 1 m long × 3 in. wide × 1 in. thick. All samples were treated with chemical preservatives from factory before drying.

Rubberwood lumber, which were grade C (had little defects), were used to determine the drying rate due to the cost saving. Moreover, the rubberwood lumber that were grade A and were dried in a drying kiln using a commercial schedule were chosen to test for the mechanical properties and compared to those (grade A) which were dried using superheated steam drying.

Before drying, small pieces were taken from each sample for moisture content (MC) determination (oven-dried weight basis). Each sample was weighed before, during and after drying. The method of calculating the moisture content from the samples was to compare the mass of the wood with its initial mass. The moisture content is calculated using the relationship:

$$MC = \frac{\text{Original mass} - \text{Oven dry mass}}{\text{Original dry mass}} \times 100\ \% \qquad (3.1)$$

The initial moisture content was approximately 90% and all wood samples were dried to moisture content of approximately 15%.

3.2 Equipment

- **Drying Vessel with electrical heater and temperature control**

A 1.8 m^3 drying vessel with 2 kW electrical heater shown in Figure E-1 was used to dry rubberwood using superheated steam and hot air. The temperature control model DD-8 was used to control temperature in the drying vessel during the drying rubberwood.

- **Vertical steam boiler (Kittipoom Equipment LTD., Part, Thailand)**

The 10 bar and 300 kg/h capacity boiler model KPB-V-300 shown in Figure E-11 was used to produce steam.

- **Lloyd Universal Testing Machine (150 kN)**

The Lloyd Universal Testing Machine shown in Figure E-12 was used to test mechanical properties of dried boards, such as hardness, compression, shear and bending.

- **Weather Conditioning Chamber**

The weather conditioning chamber shown in Figure E-14 was used to control the moisture content of dried wood before mechanical properties testing. Relative humidity (RH) conditions 65$\pm$3% at 20$\pm$2°C were employed to bring the specimens down to the required moisture content level (12%).

- **Oven**

The oven shown in Figure E-13 was used to dry small pieces of the lumber at 103$\pm$2°C to obtain the moisture content.

- **Thermocouples**

The temperature profile in the drying chamber and in the samples were measured using K-type thermocouples.

3.3 Method

3.3.1 Design and Construction of the Superheated Steam Drying Vessel

Figure 3-1 presents the schematic of the superheated steam drying operation. Steam at ambient pressure driven from 10 bar capacity boiler is heated into superheated steam using a 2 kW electrical heater, where its temperature is adjusted to the desired level, prior to being injected into a 1.8 m^3 drying chamber. The rubberwood lumber is placed on a clamped rack (shown in Figure E-10) support inside the chamber. After entering the chamber, the steam is impinged from a pair of perforated pipes located above and below the wood board. The pipes distribute the steam evenly inside the chamber (a sparging unit). A small vent releases the evaporated moisture and excess steam, and the condensed vapor leaves the chamber as liquid water through the steam trap.

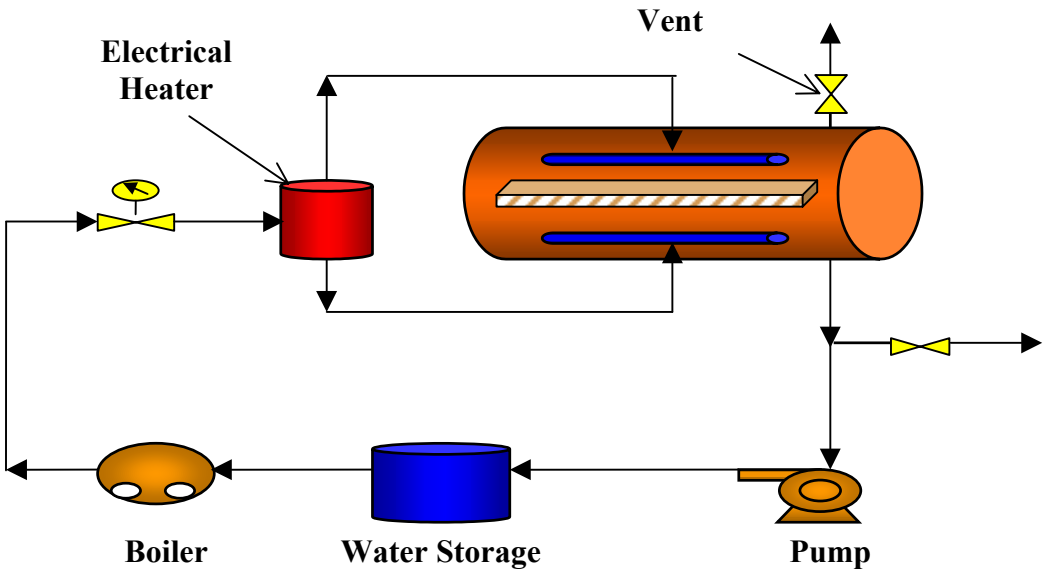

Figure 3-1 Schematic of superheated steam drying operation.

3.3.2 Determination of the Drying Rates of Superheated Steam and Hot Air Drying

Drying test were used at two temperature levels, 80°C and 110°C. The drying schedules used in the chamber are shown in Table 3-1. The lower air temperature level was chosen to be 80°C because it is typical level for drying processes in the local industry.

The superheated steam drying of the wood sample was done in the drying vessel. Samples were dried for a scheduled time and the thermocouples were placed at the desired locations of wood (Figure 3-2) to measure the wood temperatures and the temperature inside the chamber during the process.

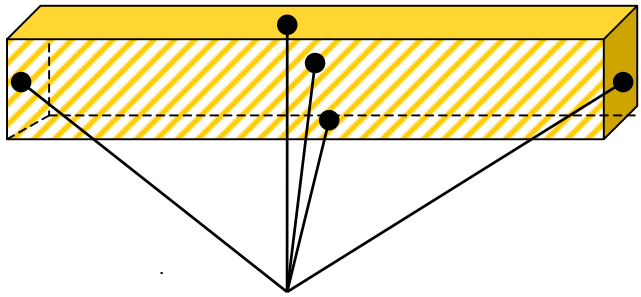

Figure 3-2 Positions of temperature sensors at lumber.

The samples were dried at various conditions as shown in Table 3-1. The scheme is repeated alternatingly until the desired moisture content was reached. Pure superheated steam and pure hot air were also used for comparisons.

Table 3-1 Experimental conditions.

Conditions	Superheated Steam (110°C)*	Hot Air (80°C)*
1	Continuous	-
2	6 hours	1 hours
3	4 hours	1 hours
4	1 hours	6 hours
5	-	Continuous

*Temperature inside the chamber

The drying rate for each condition was obtained by measuring the weight of the wood lumber after each period of drying. The amount of moisture in wood is termed the moisture content. It can be expressed as a percentage of either dry or wet basis. For most purposes, the moisture content of lumber is based on dry weight. Moisture content on dry basis is defined as follows:

$$\text{Moisture content (\%)} = \frac{\text{Weight of water in wood}}{\text{Weight of totally dry wood}} \times 100 \qquad 3\text{-}2$$

The drying rates of superheated steam and hot air drying was compared to determine the optimum condition which maximizes the physical properties of the wood (lack of stress buildup). Rubberwood lumber was dried under this optimum condition and tested for mechanical properties.

3.3.3 Determination of the Physical and Mechanical Properties

After drying, initial acceptability of the dried wood was determined using the prong test. A prong test indicates the amount of elastic stress in the wood at the time of cutting. The prongs may change their shape after cutting if the moisture content changes (Rosen, 1987).

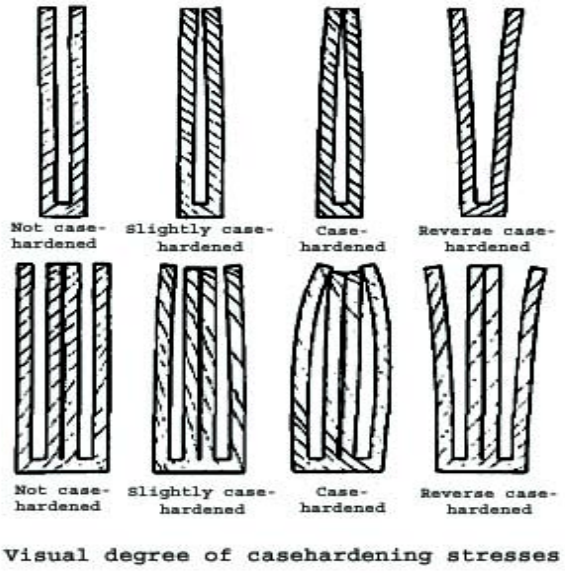

Figure 3-3 Visual degree of casehardening stresses. (Source: Simpson, W.T., et al. 1991. "Dry Kiln Operator's Manual."Agric. Handbook No. 188, U.S. Dept. of Agriculture. 274 pp.)

Method of cutting wood sections for case hardening tests are shown in Figure 3-3. Lumber is cut into three prongs, and the middle prong is removed. If the ends of the U bend toward each other slightly, the wood was deemed unacceptable due to excessive stress buildup.

After passing the prong test, mechanical testing of the dried lumber will have to be conducted. Shear tests, compression, hardness and bending were conducted on scaled specimens that conformed to the shaped specified in Kyokong and Duangpet (2000). The tests were conducted using the Universal Testing Machine at room temperature of 29°C and RH of 67%. Such testing was compliant with the

British Standard No.373 (British Standard Institute, 1987), ISO 3346, 3350, 3787 (International Organization for Standardization, 1975-1976) and ASTM D143 (American Society for testing and Material, 1980) which were modified by Kyokong and Duangpet (2000). Tests of mechanical properties of wood are shown in Appendix A.

Before testing, approximately 20 saturated specimens were randomly removed from the conditioning chamber and were immediately put into sealed plastic bags ready for mechanical testing (see Table 3-2).

Stress-strain curves obtained from tests were used to evaluate values of various mechanical properties, and for all tests, information was gathered to determine moisture content and specific gravity at the time of test.

Table 3-2 Method for testing mechanical properties by Universal testing machine.

Properties	Standard Tests for Wood
1. Shear Strength Parallel to Grain	BS 373 and ISO 3346
2. Compressive Strength	BS 373, ASTM 143 and ISO
• Parallel to Grain	3787
• Perpendicular to Grain	
3. Hardness	ISO 3350
4. Strength and Stiffness in Static Bending	BS 373

Souce: modified by Kyokong and Duangpet (2000)

3.3.4 Comparison of the Physical and Mechanical Properties of Wood

After testing for the mechanical properties, the analysis was made statistically using paired comparison design at 95% confidence level. Data obtained from the mechanical properties testing of superheated steam drying were compared with conventional drying from Rutthapoom Parawood Factory. All data were averaged and analyzed using software tool SPSS 10 for Windows.