UNIVERSITI PUTRA MALAYSIA

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Knowledge on springback and moisture uptake is necessary in assessing the potential use of bentwood in furniture industry. In this study Rubberwood was used for making bentwood. Factors such as storing condition, thickness and radius on the bending properties were studied. The specimens were plasticised by soaking in hot water for 1 hour and steamed for 25 minutes. The specimens were placed inside a stainless steel strap and pressed in a moulded hot press at three radius of curvatures (600mm, 900mm and 1200mm). The bent specimen was further heated for setting the bentwood. The springback assessments were carried out by exposing the bentwood to two different conditions: workshop (23.0 °C to 33.5 °C and RH 67 % to 96%) and air-conditioned room (25 °C and RH 70%).

The results show the springback and the moisture uptake were high in the workshop condition. Storage condition and thickness had significant effect influence on the moisture uptake and springback but radius has no significant difference.

Air-conditioned room can be used as storage for bentwood in order to minimise the moisture uptake and springback. The thicker bentwood had the lowest springback and moisture uptake. There was a strong linear relationship between the springback and the moisture uptake.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations that have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institution.

Name: ZAIHAN BIN JALALUDIN

Date: April 2000

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CHAPTER 1

INTRODUCTION

Bentwood has been widely used as various curved parts and members required for wooden products such as furniture, musical instruments, toys, barrels and sporting goods (Makinaga *et al*, 1997). In assessing the bending properties of timber, the most important factor to be considered is the minimum radius of curvature. A reasonable percentage of faultless bends can be obtained for a given thickness of clear material, both when that material is efficiently supported by means of a metal strap or when unsupported (Ser *et al*, 1987). Most tropical hardwoods have either the moderate or poor bending qualities. Tropical timbers were often found to be generally unsuitable for solid wood bending work, owing to the presence of fungi, pinholes caused by insect attack, natural compression failures or brittle heart (Anon, 1969). Using a metal supporting strap, Rubberwood can be bent to a lower curvature than Kapur (*Dryobalanop aromatica*), Meranti temak (*Shorea hypochra*), Meranti temak nipis (*Shorea roxbughii*) and comparable to Meranti sarang punai (*Shorea parvifolia*) (Ser *et al*, 1987).

The wood of six commercially important Indian timber species gave satisfactory bends of radius 100-175 mm in 13 and 25 mm thick strips when plasticised with ammonia at 5 kg/cm^2. The woods were *Acrocarpus fraxinifolius, Grevillea robusta, hevea brasiliensis, Morus alba, Populus deltoides and Tectona grandis* (Pandey.C, 1995). The bending ratings of Chinese guger-tree were influenced by the thickness of the specimens and its curvature. Percentage of acceptable bentwood increased with decreasing thickness and increasing radius. Statistical analysis also indicated that the final curvatures of the bentwood correlated with the degrees of instantaneous recovery (Chin, 1988). According to Zhang (1987) changes in radius of curvature depended only on changes in moisture content.

Statement of Problem

The problem of springback has influenced to some extent, the popularity of solid wood bending. During the bending process, tensile and compression, strains are induced to the material. The material is usually strained beyond its elastic limit so that some permanent deformation of the fiber occurs. For this reason, a bend that is allowed to move seldom returns completely to its former shape. When, however, the induced strains are below the elastic limit, removal of all restraint results in almost complete removal of the strain in the fibres and hence the piece will return very nearly to its shape (Steven, 1970). Similarly, the intention to release the tension back to the natural matrix of the normal wood is severed if the bentwood is exposed to a hot condition and high relative humidity. Therefore, to overcome this matter the bentwood must be dried to appropriate moisture content and placed in a conditioning room. In these study parameters such as thickness, radius and condition related to the effect of springback were studied to evaluate the critical factors for the springback.

Justification

Moisture content affects both the physical and mechanical properties of bentwood. An increase in moisture content after the bending process causes the radius of the bentwood to springback hence, increasing the radius of curvature. On the other hand, a decrease in moisture content also causes the radius to decrease. Bentwood, when subjected to high humidity conditions for a long period of times may open out considerably and may not return to its original shape and curvature when redried. The bending ratings are also influenced by the thickness of the specimen and its curvature. This study seeks to evaluate the behaviour of different thickness and radius bentwood when subjected to different conditions; a workshop and an air-conditioned room.

Objectives

The objectives of this study were:

a) To determine the effects of wood thickness and radius of curvature on the springback of bentwood

b) To evaluate the effect of reconditioning period on the moisture uptake and springback of bentwood

CHAPTER 2

LITERATURE REVIEW

Rubberwood

Rubberwood is the common Malaysia name for the timber of *Hevea brasilienses*. It is classified as a light hardwood with an average air-dry density of 640kg/m^3. The wood is whitish yellow when freshly cut, and seasons to a pale cream colour; with pinkish tinge. It has moderately coarse but even texture and straight to shallow interlocking grain. The timber is easy to saw, crosscut and machine (Hong *et al*, 1994). The rubber tree is a valuable raw material for further processing into furniture, joinery household items and other finished items. According to Ser *et al* (1980), Rubberwood has the potential for solid bent works, particularly for furniture components, which do not demand a sharp curve.

Wood Bending Technology

Wood bending by steaming or boiling has been known since ancient times. The practice of bending timber dates back to antiquity when man first learn to make basket from osier and shipwright no longer contented themselves with making boats from hollowed cut logs. It has been reported that its commercial application started in the early 18th century in some European countries. However, the technology has been fully exploited only after 1840 when Austrian cabinet-maker experimented on a curvilinear design in his wooden chair (Anon, 1992). According to Steven (1970), in the 18th century many craftsmen produced boat stem, where they hewn or sawn from limbs of trees having a curvature roughly the same as that required.

Early 19th century witnessed the change in solid wood bending technology whereby two main methods were introduced. The first method was by softening and bending the complete piece in the solid form and the second was by bending and gluing together a number of thin lamination or plywood strips to produce required dimension and curvature. To improve solid wood bending, the selection and preparation of bending material are most important. The selection was based on the quality, species, density, moisture content and machining property of the wood (Steven, 1970). Other methods used to soften solid wood were steaming, microwave heating, boiling and chemical treatments. Steaming (Anon, 1984) means, placing wood in a steam bath to make it more elastic for bending, peeling or slicing. In Philippine the local timber indicated satisfactory plasticization of 25mm thin wood with 25% moisture content by steaming at atmospheric pressure and 100 °C or soaking in boiling water for 45-60 minutes (Mendoza, 1984). Chemical treatment process has been developed in US in 1969 for making wood pliable by dipping in a liquid anhydrous ammonia at 33°C (Steven, 1970). The use of anhydrous ammonia, in the liquid or vapor phase, permits the bending of many woods in much more complicated shapes than the method of steam bending (Meyer, 1984). According to Norimoto (1989) one of the new technique of wood bending was a microwave irradiation which used to heat and soften wet wood specimens. Microwave heating efficiency in wet wood is very high because most of the wave energy absorbed by the water.

In the developed countries particularly, Japan wood bending technology has been the main focus in furniture design. One of the most frequently studied field is in solid wood curvature because solid wood is usually jointed before being bent. Hence the bending process is time consuming and requires high maintenance (Anon, 1992).

Thonet Method and An Evolving Product

Bending of wet wood into chair parts legs, bows, arms, etc., and was practiced by country woodworkers from the earliest times and has its roots in the ancient craft of willow bending. The first known type of bentwood furniture is the Windsor chair. It is already existed in England by the 1500s and introduced the typical feature of a bentwood back frame, later extending to the curved armrest and stretcher components. The craftsmen who first produced the Windsor chairs bent their material with the help of steam, using mainly beech, but also ash, as the main raw material.

Circa 1840, Michael Thonet began to develop the first truly industrial basis for wood bending by working out a technology that relied on a steam power (Anon, 1994). Having foreseen a mass market for bentwood furniture, Thonet set out to develop a range of chair designs suitable for mass production. From the point of view of product engineering his main intuition was to create a standardised chair structure consisting exclusively of interchangeable bentwood components jointed together by metal fasteners. This in turn led the production, on an industrial basis, of first ready-to-assemble standard chairs. One of Thonet's particular chair design models, known as Chair No.14, typifies the characteristics of bentwood furniture:

- Structural efficiency and ingenuity essentiality of components
- Lightness and airy appearance adaptability to bulk shipment (as many as 36 units of a typical bentwood chair could be packed into one cubic metre)
- Suitability to providing ergonomical posture

Solid Wood Bending

The Principal of Wood Bending

When the boiled or steamed wood is bent, the fibers on the inside of the curve are compressed while those on the outside must stretch. Since the wood is stronger in compression than in tension, a steel back-up metal strap with fixed end-stops is commonly used to restrain the length of the blank, thus shifting most of the stress into compression. If the strap is too loose, tension failure is likely result the wood fibers on the convex side of the bend stretch until they break. If this strap is too tight, the fibers on the inside of the curve may wrinkle and buckle, called compression failure (Anon, 1984). This distortion is caused by stresses which also tend tend to bring the bent piece back to its original straightness when released.

Moisture Content of Bentwood

Although green wood can be bent to produce many curved members, difficulties are encountered in drying and fixing the bend. Another disadvantage with green stock is that hydrostatic pressure may be developed during bending. Hydrostatic pressure may cause compression failures on the concave side if the wood is compressed by an amount greater than air space in the cells of the green wood. For most chair and furniture parts, the moisture content of the bending stock should be 12 to 20 percent before it is steamed. The preferred moisture content varies with the severity of the curvature to which the wood is bent and the method used in drying and fixing the bend member (Anon, 1987).

Softening Treatment

In order to render timbers plastic and compressible so that they are in the best possible condition for bending, a supply of heat and moisture must be made available. Heat and moisture together can produce a degree of plasticity which roughly 10 times that of dry wood at normal temperature (Anon, 1992). Steamed can be compressed 25 to 30% along its length but can be streched 1 to 2% only (Anon, 1987). The moisture in the steam supplements the initial moisture content of the wood especially in those fibers near the surface. Industrial research has also found that air dried wood at a moisture content of 15% to 20% is best for steaming but some species of kiln-dried wood at 8% to 12% MC showed a good success (Anon, 1984).

Bending Operation and Apparatus

After being plasticised, the wood should be quickly placed in the bending apparatus and bent to shape. The bending apparatus consist essentially of a form (or forms) and a means of forcing the piece of steamed wood against the form. (Anon, 1987). Traditionally bending operation can be done manually by using hand technique but by the increasing demand for bentwood products, various kinds of machines such as lever-arm, hot-press and roller press has been invented and commercially uses.

Fixing The Bend

After being bent, the wood should be cooled and dried while held in its curved shape. One method is to dry the piece in the bending machine between the plates of a hot-plate press. Another method is to secure the bent piece to the form and place both the piece and the form in a drying room. When the bent member has dried to a moisture content suited for its intended use, the restraining devices can be removed and the piece will hold its curved shape (Anon, 1987). High frequency heating is one of the method that can dry the bentwood in a short period. High frequency heating depends on the principle that, when two metal electrodes are connected to a source of electric current alternating at high frequency, heat is generated in non-metallic materials situated between the plates (Anon, 1994).

Characteristic of Bentwood

After a bent piece of wood is dried, the curvature will be maintained unless the wood undergoes changes in moisture content. An increase in moisture content causes the piece to loss some of its curvature. A decrease in moisture content causes the curve to become sharper; although repeated changes in moisture content bring about a gradual straightening. These changes are caused primarily by lengthwise swelling or shrinking of the inner (concave) face, the fibers of which were wrinkled or folded during the bending operation (Anon, 1987).

Factors Affecting the Properties of Bentwood

Wood Moisture Content Variations

Moisture loss or gain below the fiber-saturated points is always accompanied by dimensional change. For all practical purpose, the dimensional change is linearly related to the moisture change (Bodig and Jayne 1982). Changes in the equilibrium moisture content (EMC) and subsequent changes in dimensional are important aspect of the physical and mechanical properties of wood. The moisture in wood exist in two basic forms: bound water is dissolved or desorbed in the hygroscopic cell wall and free water or capillary water which is situated in the voids within the wood. An equilibrium moisture content increase with the relative humidity from essentially zero in dry air to approximately 30% of oven dry weight at 98% relative humidity and theoretically to full saturated of all voids at 100%. Relative humidity is the ratio of the partial vapor pressure in the air to the saturated vapor pressure, expressed in percent.

Wood Species

In general, hardwoods particularly those from the temperate region show better bending quality than softwoods (Anon, 1987). However, basic wood properties, which may serve as indices of bending quality, remain to be fully examined. Mendoza (1984) reported that most Philippine woods with higher density and modulus of elasticity (MOE) may be bent to shorter radius than those with lower density and MOE. Patterson (1991) added that highly lignified species are more resistance to bending. The selection of bending wood is largely governed by the suitability and availability of a species used in the manufacture of articles in which the bentwood to used. Straight-grained, clear material is best for bending. The presence of serious cross grain, knots, decay, surface checks or split, shake, pitch pocket and brash wood leads to undue fracture even with slight bending.

Cutting Pattern

Plainsawn rather than quartersawn material is preferred as bending stock particularly in species with prominent medullary rays (Natividad & Soccoro,1992; FCNSW 1988). The rays cause wrinkling on the concave face in bent quartersawn boards.

Air Temperature

Air temperature is a major factor that influenced the water movement in wood. It is needed to speed up the movement of moisture in wood. High temperature creates more rapid moisture movement than low temperature.

Relative Humidity

The relative humidity is the amount of moisture in air at a given temperature compared to the saturated amount it will hold at the same temperature. The relative humidity (RH) of air is directly proportional to the moisture content of wood. A lower RH means a faster evaporation from the wick, a faster rate of heat removal and air temperature.

Air Circulation Speed

Air circulation or wind is required to remove moisture absorbed from the drying wood and to convey heat to wood. The velocity of air circulation is an important factor that contributes to the movement of the moisture.