Mokchae Konghak 29(3) : 14~20, 2001

Effect of a Metal-strap Thicknesses on the Bending Process*[1]

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ABSTRACT

On the bending process, metal-strap plays an important role in dispersing the stress generated in wood. Therefore, the metal-strap has more influence on the property of bentwood materials. The effect of the metal-strap thickness for bentwood was examined.

The effect of metal-strap on the bending properties of Korean red pine(*Pinus densiflora* Sieb. et Zucc.)was investigated in this research. The metal-strap thickness is divided into 4 kinds such as 1.0, 0.8, 0.6, 0.4 mm. The specimens were selected by grain such as annual ring angles, flat grain and half-edge grain specimens.

As a result of this study, the bending abillity of 1.0, 0.8 mm, thickness of half-edge grain specimens was better than flat grain specimens but the result of 0.6, 0.4 mm were reversed. The bending ability of half-edge grain was better than flat grain and the grade was higher. When the processed specimens were dried, the radius of curvature(ROC) was decreased became drying-stress was not perfectly dispersed. An optimum drying-condition would deminish this phenomenon.

Keywords : Bending, metal-strap, radius of curvature(ROC), ratio of strain, flat grain, half-edge grain, bending jig

1. INTRODUCTION

The production of bentwood furniture was quite interesting field for its beauty and benefit before it represented one of the first example of industrial production. In the middle of the 19th century, M. Thonet established an effective technique of bending wood based on steam pre-treatment with a drying set.

This technique was introduced to many countries all over the world. Today, it is still widely used in the furniture, musical instrument, and other industries virtually with no improvement. Michael Thonet, German, belongs to the title of inventor of the process of production and of designer of the models, even though

*1 Received on June 4, 2001, accepted on August 24, 2001
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some cabinet-makers had tried before his attempt to produce furniture with the same procedure.

Some models, especially those rich and complicated, chair like no. 22 (Figure 1, around 1880), often splitted easily where the bending process drastically changed the original shape of the wood and had processed beyond its natural elasticity. To solve this inconvenient property was the idea that attaching a metal-strap at both ends of the rods and then to begin the bending process. However it has many difficulties for bentwood, because wood is an anisotropic material. In case of the traditional bending method, it is possible to bend solid wood by the method of heat softening treatment, sawing kerf, chemical treatment and so on (Jung, 1992). Recently, a new bentwood method called Denmark method was developed using the longitudinal compression of solid wood by the Compwood company in Denmark. But, in practice, the material selection is difficult since this bending process method requires a straight grain and no defects.

The bending quality of wood varies widely among the different species and also within the same species. Actually, solid wood suitable for bending processing is restricted to some wood species, especially for soft wood rather than hard wood, special. Today, the supply of good bending quality hardwoods is decreasing, and in the future, more and more softwoods with low bending quality will be required.

And the concern about the utilization of softwood resources is recently rising due to an exhaustion of hardwood resources. In these complicated circumstances, the research and development of new bending techniques for softwoods, for instance Korean red pine, is very desirable. It was found that the role of grain angle of solid wood specimens was important to the bending process. With an increase of wood grain angle, solid wood can be easily bent without defects. However, in this case the bending strength of the bentwood with large grain angle is very weak.

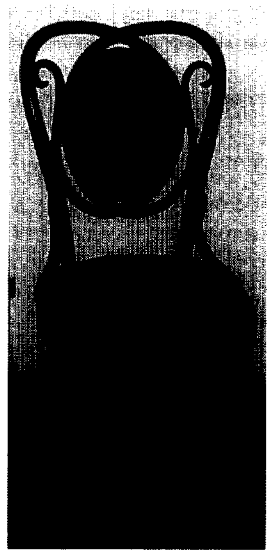

Fig. 1. Picture of a typical Thonet's chair.

Furthermore, the defects of bentwood were occurred at both the particular collapse on the inner side and some cracks on the outer side of the bend, respectively. When a wood piece is bent, the outer side of the bend is stretched while the inner side is compressed. This phenomenon is considered the results of complicated relationships among stress distribution, metal-strap, wood property and etc. Especially, when the thickness of metal-strap to restrain tension strain is small, it is considered that the equilibrium of stress distribution for bending is broken. As a practical point, the purpose of bending is to compress the wood while restraining the stretching along the outer side of bentwood.

This study was conducted to investigate the effect of metal-strap thicknesses and modulus of elasticity (MOE) of specimens on the bending process.

2. EXPERIMENTAL

2.1 Specimen and method

Wood specimens for bentwood were made from Korean red pine (*Pinus densiflora* Sieb. et Zucc.). The dimensions were 330(L)×10(R)×20 mm(T). The thickness for the bending process of wood was a radial direction. A metal-strap, carbon steel with wood handle at both ends was needed to restrain the stretching along the outer side of wood specimen. This might be achieved by fixing the wood specimen on a metal-strap because it absorbed most of the tensile stress during the bending operation. The metal-strap was four kinds such as 0.4, 0.6, 0.8, 1.0 mm. Sixteen specimens were alloted to each bending operation conditions. The radius of curvature (ROC) of wooden form were 7 and 9 cm. The specimens were dried in oven-dryer at 105°C and conditioned to 12% moisture content (MC) at 20°C and 65% relative humidity (RH). Bending test (three-point bending) was performed to obtain MOE for 30 seconds using an universal testing machine (HOUNSFIELD. H50K-S). The cross-head speed was 2 mm/min and the span size between the outer supports was 150 mm. After the determination of MOE, all wood specimens were vacuum-treated using water to obtain 180% MC. Saturated specimens were heated with microwaves for 90 seconds up to about 100°C and bent using a metal-strap device. Then in order to obtain the permanent fixation, bentwoods were dried for five hours in oven dryer at 90°C in the restrained state. These bentwood specimens were conditioned at 20°C, 65% RH for about 2 weeks prior to the evaluation of curvature and compressive strain of bentwood.

2.2 Measurement of radius of curvature (ROC)

As shown in Figure 2, it set up a distance of horizontal line(a) and vertical line(b) on the inside diameter of a geometrical figure. Based on Figure 2, ROC (ρ) and strain(ε) by bending deformation is expressed by equations (1) and (2).

$$\rho = \frac{a^2+b^2}{2b}, \quad L = 2\rho \cdot \sin^{-1}(a/\rho) \tag{1}$$

$$\varepsilon = \frac{|L-L_0|}{L_0} \times 100 \tag{2}$$

L : deformed length after bending,
L_0 : original length of specimen.

3. RESULTS and DISCUSSION

3.1 Factors

First of all, it was considered that the important fact on wood bending operation was

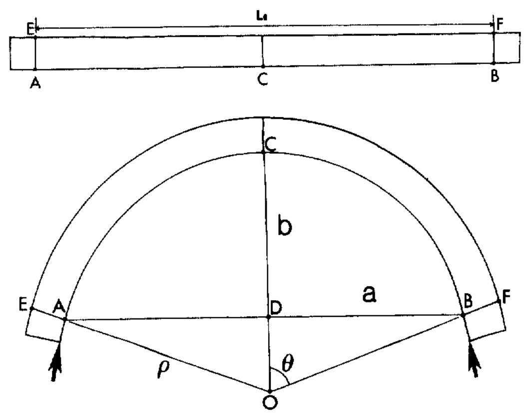

Fig. 2. A model illustrating the bending deformation for curvature and strain calculations. Distance of line BD and CD(lower) indicates a and b in the equation (1), respectively. Lo(line AB or EF), ρ is the original length of base line and radius of curvature, the line AE and BF (upper) are base lines for the strain estimation.

to make the bending resistances of wood specimens weaker. In general, the resistance index for wood strain was given the modulus of elasticity (MOE) of wood.

Therefore, the research on reducing MOE of wood material is important to decrease the problem of the crack appearance and a partial collapse of bentwood. Norimoto and J. Gril (1989) studied the relationships between Young's modulus (MOE) and apparent breaking strain in the radial direction for 14 Japanese hardwoods, 12 Japanese softwoods and 12 tropical woods by 3 points bending test. They reported that dry wood was strong and brittle, but both moistening and heating, decreased MOE and increased breaking strain. A similar trend was observed for all wood species used in this study regardless of the direction of applied stress. In previous report, it was found that the MOE of wood greatly decreased with the increasing the slope of wood grain. An other factor of reducing index MOE was microfibril angle. It was related to the winding angle of the cellulose microfibrils in the S_2 layer of softwood tracheids. Cave (1968) reported that the stiffness of the cell wall increased enormously from pith to cambium as the microfibril angle decreased from 40° to 10°. Also, Cave(1968) reported that the MOE of wood with high fiber inclination angle made wood excellent bending material. In this case, however, the most important factor was the thermal softening of cell wall composition. Cell wall contains about 50% cellulose and 20~30% hemicellulose and 20~30% lignin.

Bound water is held in the cell wall and acts as both a swelling agent and a plasticizer. Cellulose is degraded below its glass transition temperature. However glass transition temperatures of hemicellulose and lignin are 167~217 ℃ and 134~235℃, but decreased to 54~142℃ and 77~128℃ in the wet condition, respectively (Goring, 1963). Therefore, the heating of wet wood results in further softening of the wood cell wall.

Table 1 shows the relationship between MOE and ROC and other bending factors. In this table, the MOE values of flat grain wood was much greater than that of half-edge grain wood, and the amount of deformation flat grain wood was smaller than that of half-edge grain wood within the same jig ROC. And the curvature of bentwood after drying for permanent fixation decreased when compared with the state of before drying. This phenomenon might be explained by the shrinkage of inner side of bentwood as the moisture was reduced by the drying process to obtain the permanent fixation of bentwood.

The strain after drying of 9 cm bentwood ROC was larger than that of 7 cm bent wood ROC. From these results, it was found that a large ROC of bentwood was larger than a small ROC of bentwood. Probably, the increase of compressive strain of bentwood was believed to cause a large shrinkage in the inner side of the

Table 1. Relationship between Young's Modulus and radius of curvature after bending.

Radius of curvature on jig plate	Radius of curvature after bending (cm)	Strain after drying (%)	MOE (kgf/cm^2)	S.G O.D (g/cm^3)	S.G 13% (g/cm^3)
7 cm (Flat grain)	6.78	22	57.54	0.44	0.47
7 cm (Half-edge grain)	6.79	21	33.21	0.40	0.44
9 cm (Flat grain)	8.72	28	60.93	0.42	0.46
9 cm (Half-edge grain)	8.62	38	45.45	0.42	0.45

Note) O.D: oven-dry

bend. However, the reason of this phenomenon was not clearly understood yet.

Consequently, there is a need of considering the ROC and thickness of metal-strap. Furthermore, it was required to design the bending jig for faultless bentwood production.

3.2 Bending ability depending on the thickness of metal-strap

3.2.1 Radius of curvature (ROC)

In Figure 3, the changes of ROC after bending were similar except in the case of 0.4 mm thickness of metal-strap. The ROC of bentwood specimens of 7 cm jig ROC was not apparently different between different thicknesses of metal-straps. But the ROC of bentwood specimens of 9 cm jig ROC was slightly reduced with decreasing of metal-strap thicknesses.

In particular, the 9 cm ROC on bending jig could be observed its tendency of a change. Therefore, we decided to use a thickness of metal-strap enough to prevent the stress generated while drying. It was possible to get the stability of dimension. And if was used, these would be little effect to disperse the stress and generate a large deformation.

According to the result of this study, when thickness of specimen was about 10 mm, it was a good method to use over 0.8 mm to minimize the deformation of ROC. It was judged to reduce the cost if suitable thickness was used according to species and materials thickness.

3.2.2 Estimation of bending ability and ratio of strain

So and Chai (1992) studied about bending process using *Robinia pseudo-acacia* for bentwood furniture materials by microwave-heating. When the thickness of specimens was

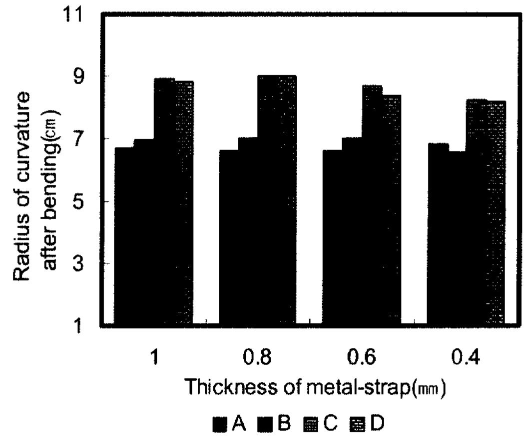

Fig. 3. Relationship between the radius of curvature (ROC) and the thickness of metal-strap;
Legend) A : Flat grain specimen (ROC=7 cm)
B : Half-edge grain specimen (ROC=7 cm)
C : Flat grain specimen (ROC=9 cm)
D : Half-edge grain specimen (ROC=9 cm).

15 mm, the minimum solid bending radius of black locust was 40 mm for water vapor steaming and 150 mm for microwave heating, respectively. They evaluated the bending ability with 4 grades as follows: 1) without failure, 2) minor compressive failure on the inner side, 3) remarkable failure, and 4) broken.

In this study, however, bending ability is divided into 3 grades because of no breakage on the inner side for all bentwoods. The three grades were:

C : Width deformation along one line compressive failure on concave side.

B : A little compressive failure that can be removed by sanding along the width and thickness direction.

A : Without compressive failure remarkably.

As shown in Table 2, the evaluation of bending ability of Korean red pine as A and B grade indicated a possibile application of bending process, and C grade indicated a failure by excessive compressive strain.

Table 2. The estimation of bending property in Korean red pine by microwave heating.

Thickness of metal-strap	Number of flat grain specimens		Number of half-edge grain specimens		Grade of bending ability			Number of specimens. (A+B Grade)	Number of total specimens. (A+B Grade)
	7 cm	9 cm	7 cm	9 cm	A	B	C		
1.0 mm	0, 2		2, 4		4	4	8	16(8)	
0.8 mm	0, 2		4, 2		6	2	8	16(8)	64
0.6 mm	2, 2		0, 2		6	0	10	16(6)	(30)
0.4 mm	2, 2		0, 4		2	6	8	16(8)	

Note) A: Excellent, B: Good, C: Fail Parenthesis is the sum of A and B grade

Bending ability of half-edge grain wood showed similar results to So's work(1985). Therefore, it was considered that bending ability is more affected by grain angle of wood rather than the thickness of matal-strap. In the same experimental conditions, the bending ability of the 1.0 mm metal-strap thickness was better than that of the 0.4 mm metal-strap thickness. In general, the number of successful bending specimens was appeared to similar for both flat grain and half-edge grain specimens. But, in a detailed examinations, it was found that the bending ability of half-edge grain wood with 1.0 mm and 0.4 mm metal-strap thickness was shown slightly better bending process than that of flat grain wood. In the case of 0.6 mm for metal-strap thickness, it could be successfully operated without defects regardless of annual ring angle. The interlocked grain was observed on the surface of some failed specimens. Therefore, at the present stage of the same wood species, the grain selection is important factor for the improvement of bending ability. Compressive strain on the inner face of bend was calculated and divided to A and B grade, and the results were shown in Figure 4.

There was no A and B grade in thickness of 1.0 mm 0.8 mm because all specimens flat grain of the C grade of the 7 cm jig ROC. both 0.6 mm and 0.4 mm for half-edge grain were C grade for the 7 cm jig ROC. This result was

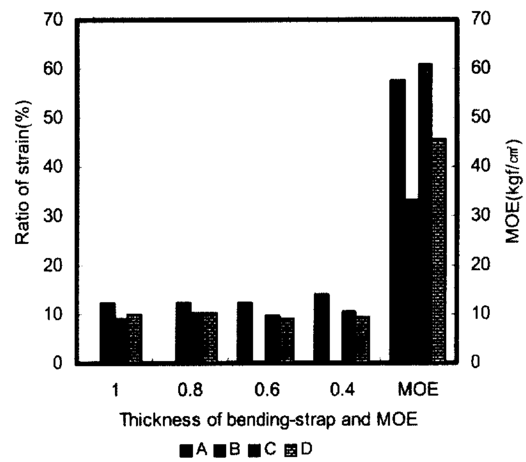

Fig. 4. Relationship between the thickness of a metal-strap, MOE and the ratio of strain.

considered that the shock-absorbing of the tensile stress was happened to increase of the MOE and thickness of metal-strap. However, its correlation was not known clearly. In the thickness of metal-strap above 0.8 mm, bending operation of flat grain wood was very difficult for a metal-strap cannot absorb the tensile stress shock.

Consequently, when the thickness of metal-strap was thicker, bending operation of flat grain wood was very hard to bend.

On the other hand, when the thickness of metal-strap was thinner, bending operation of half-edge grain wood was also very difficult. Therefore, the selection of suitable thickness of metal-strap was very important factor related with the wood species and the shape of wood grain.

4. CONCLUSION

As the results of this study, bending ability of half-edge grain wood was excellent for thicker metal-strap. In annual ring angle, the bending ability of half-edge grain wood appeared better than that of flat grain wood.

1.0 and 0.8 mm, of half-edge grain showed specimens bending ability better than flat grain specimens but 0.6 and 0.4 mm were opposite.

When the processed specimens were dried, the ROC was decreased. Because drying-stress was not perfectly dispersed. Finding an optimum drying condition could deminish this phenomenon.

ACKNOWLEDGEMENT

This study financially supported by Agricultural R&D Promotion Center.

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