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Development of Thin Wood Bending Teaching Materials in Technological Education in a Japanese Junior High School

Kiho Jung [1*], Takahiro Shirai [1], When-Shao Chang [2], Yusuke Suzuki [3]

[1] *Shizuoka University, Shizuoka, JAPAN*
[2] *University of Sheffield, Sheffield, ENGLAND*
[3] *Shimada Daiyon Elementary School, Shimada, JAPAN*

* CORRESPONDENCE: ✉ jung.kiho@shizuoka.ac.jp

ABSTRACT

As an effective teaching material aimed at improving technological literacy by attracting the interest of students in the technological education curriculum in a Japanese Junior High School, teaching material using thin wood bending was the focus of this research. The integrated teaching material using thin wood bending was developed and introduced into the Junior High school in order to improve student's technological literacy. For further application as teaching material, bending mechanisms and optimum bending conditions were verified by experimental investigation based on theoretical considerations. The results of a questionnaire survey during teaching practice in Junior High School found that it showed high effectiveness and potentiality as a teaching material. Furthermore, the bending mechanism of the thin plate by mechanical analysis was verified by evaluating the change of tensile and compression properties with a relatively higher temperature (near to the boiling point of water) under higher MC (Moisture Content) conditions over FSP (Fiber Saturated Point). Therefore, it could be numerically predicted on the optimum bending curvature for thickness of plate, for improving the original design with theoretical understanding of student on the thin wood bending material.

Keywords: thin wood bending, integrated teaching material, technological literacy, tensile and compression properties

INTRODUCTION

Japanese technological education consists of four different fields: (1) materials and processing; (2) energy conversion; (3) information; (4) raising organisms. There are embedded in the curriculum of Junior High schools in Japan. Recent debate has shown the need for integration of these four fields together with technology-led teaching and learning.

This paper focuses on teaching material dealing with thin wood bending technology, utilising the characteristic thermal plastic property of wood on a high MC (Moisture Content) condition over FSP (Fiber Saturated point). The thin wood bending technique has been used for making traditional wooden boxes like "Magewappa" in Japan, as shown in **Figure 1**.

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Figure 1. Example of introduction for Japanese traditional product "Magewappa" using thin wood bending in Junior High technology book

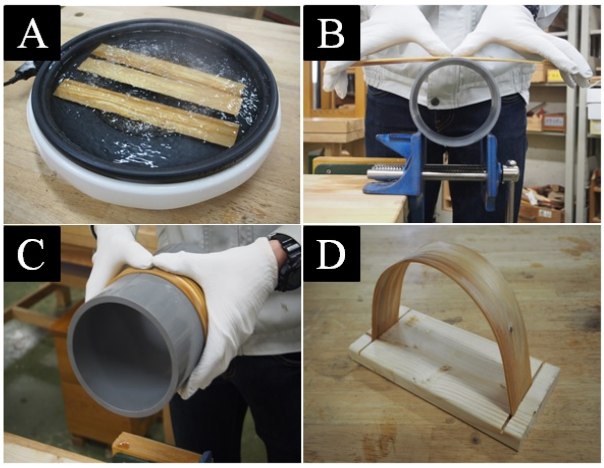

Figure 2. Bending process
Notes: A) Heating; B) Bending; C) Shape forming; D) Drying and curing.

As a first step, teaching material using thin wood bending was suggested and verified for effectiveness using a questionnaire in teaching practice. The bending mechanism was verified by compression test and tensile test with relatively higher temperatures (near to the boiling point of water) over FSP condition. Then the optimised condition for bending was estimated by mechanical model. The final goal of this research is to suggest effective teaching material using thin wood bending, with the aim of the easier study of technologic literacy through attracting the interest of students.

The Process for Making Thin Wood Bending

The thin wood bending making process has 4 steps: (A) heating; (B) bending; (C) shape forming; (D) drying and curing, as shown in **Figure 2**. The bending operator needs to wear both heat protective and waterproof gloves to protect their hands from hot water during the bending process e.g. waterproof latex gloves over thick cotton ones. The bending process is performed using a cylinder gigue like PVC pipe, round wood, a bottle and so on at a condition of higher temperature (Just after 10 min boiling in water) using a 2~3mm soft wooden plate like spruce (*Picea abies*), Japanese cedar (Cryptomeria japonica), Japanese cypress (*Chamaecyparis obtusa*), on relatively higher condition than FSP by long term insertion in water over 3 weeks. This is followed by a drying and curing process in a fixed condition for one week.

Teaching Materials Using Thin Wood Bending

In technological education in Japanese Junior High schools, woodworking is the most important practical course because wood can be easily processed by sawing, assembling and fixation by nailing, balanced with

Figure 3. Thin wood bending products (Free design)

Figure 4. Front-Loading-Horn stand for ICT device

Figure 5. Horn Speaker Amp system using 3 pieces of thin wood bending

originality and structural function. Recently, this course has widened to Elementary schools so as to teach about the most beneficial natural resources in the carbon neutral cycle for establishing a sustainable society.

Wood bending can be a better way for students to find out about original and varied design, as shown in **Figure 3**. Furthermore, thin wood bending can be introduced into the latest modern products integrated with mechanical or electrical parts, as shown in **Figure 3** to **Figure 6**, examples of the benefits of wood bending.

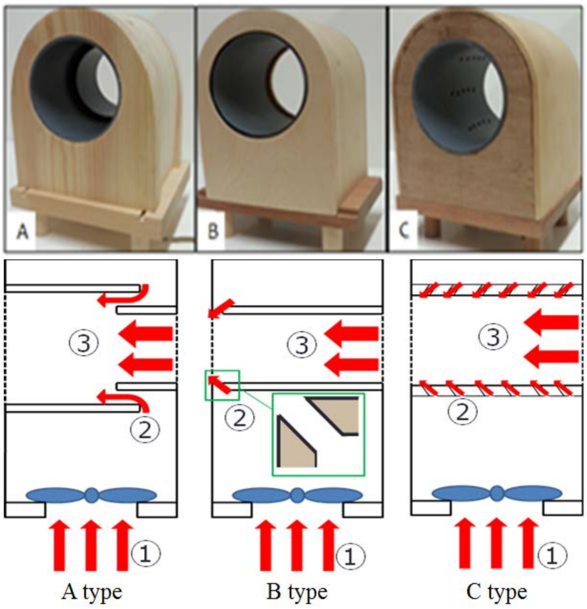

Figure 6. Non-Blade-Fan

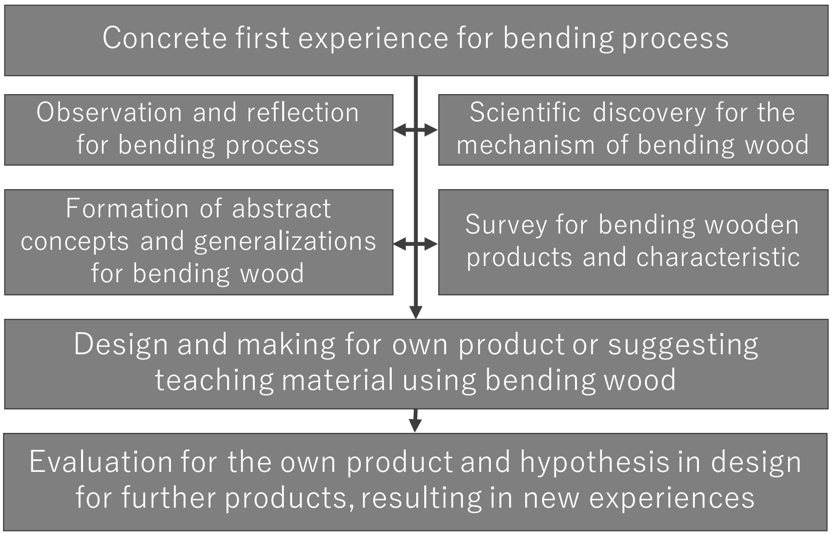

Figure 7. Learning process by wood bending teaching material designed using Kolb's Learning theory

LEARNING THEORY FOR WOOD BENDING TEACHING MATERIALS

Based on Kolb's Learning theory, technological education using thing wood bending teaching material can be effective as hands on and experiential.

Generally, wood is relatively difficult to bend without failure and to keep its shape with bending is common sense, compared to materials like plastic or soft iron. This originates from its characteristic cell structure. Thus, most students have this set idea; that a certain diameter of soft iron stick bends well, but that a wooden stick is easily broken.

However, a certain size of wood can bend with designed curvature and keep its shape using special techniques by craftsman with experience or a scientific background. It can then be used as parts of products to satisfy a designer's demands. In this research, it is thought that the new experience of the bending process helped students to understand the scientific behaviour of wood. Originally designed teaching material gave them the chance to develop products which were different from the usual, and integration with other fields can make technological education more widely effective.

Figure 8. Bending process in the teaching practice

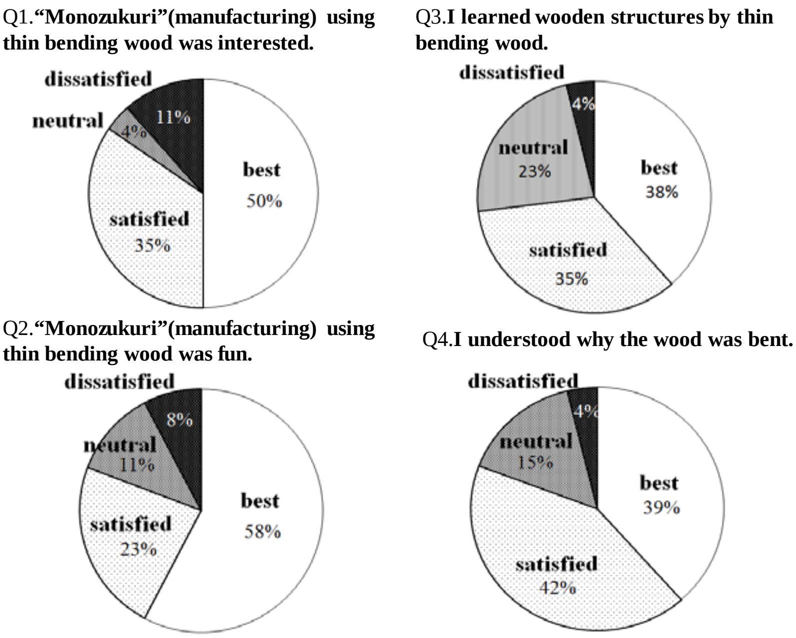

Figure 9. Questionnaire

TEACHING PRACTICE

The purpose is the inspection of its effectiveness as a Junior High School teaching material. 27 students 7th grade and 146 students 9th grade participated.

All students made wooden products with free design using thin wood bending.

A questionnaire on the teaching practice, as shown in **Figure 9**, mainly focused on student interest and knowledge gained in order to evaluate the effect of teaching material using wood bending.

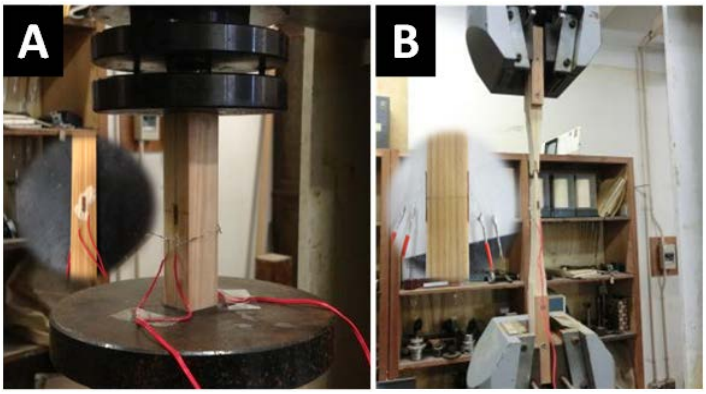

Figure 10. Apparatus of each material test.
Notes: A: compress test; B: tensile test

A) Interesting

Q1: "Monozukuri" (manufacturing) using thin wood bending was interesting.

Q2: "Monozukuri" (manufacturing) using thin wood bending was fun.

85% of students for Q1 answered 'best' or 'satisfied'. 81% of students for Q2 answered 'best' or 'satisfied'. It was thought that the bending process was very effective in attracting students' interest.

B) Knowledge

Q3: I learned about wooden structures by bending thin wood.

Q4: I understood why wood bends.

73% of students answered 'best' or 'satisfied' about Q3 and 81% answered it about Q4.

The questionnaire shows that teaching material using thin wood bending has high effectiveness in technological education.

EVALUATION OF BENDING MECHANISM AND INVESTIGATION OF OPTIMUM CONDITIONS

Bending Mechanism and Optimum Conditions with High Temperature over FSP

The thin wooden plate (thickness: 2~3mm) with high temperature over FSP (Fiber Saturated Point) condition can bend until a certain curvature (diameter: 100mm) is achieved, while it will be broken without heating in drying conditions due to tensile failure in the outside of thin wood. It is expected that the success of bending in this condition is dependent on the change of compressive properties in the inner side and tensile ones of the outer side of thin wood by beam theory.

Hence, investigation of bending mechanisms by evaluating the relationship between tensile and compressive properties at a high temperature over FSP can verify optimal conditions between thickness and curvature.

Change of Material Property with High Temperature over FSP

All specimens for the material test were made as JIS standard. The species was Japanese cypress (*Chamaecyparis obtusa*). 3 groups of materials were selected and classified to each 10.5GPa, 12.4GPa and 13.6GPa of dynamic Young's modulus by FFT analysis. Twice the number of specimens was prepared for comparison of normal and high temperature over FSP conditions. Two strain gauges were attached to both sides of the specimen, as shown in **Figure 10**.

Tensile and compressive tests on the normal condition were performed with a universal test machine (TCM10000), as shown in **Figure 10**. Crosshead speed was 1mm/min for each test. On the condition with high temp over FSP, a wet specimen was used after immersion into water for more than 3 weeks and an average 200% at measuring of MC. Compressive testing was performed immediately after 10 minutes boiling, and the tensile test was performed after reaching near 100°C with heating gauge as shown in **Figure 11**.

Figure 11. Tensile test with high temperature over FSP

Table 1. Changes of tensile and compressive properties by high temperature over FSP

Compress	yield stress	Stiffness
	MPa	GPa
Dry	35.5	2576
heated and wet	14.4	2554
rate of variability	60%	1%
Tensile	**yield stress**	**Stiffness**
	MPa	**GPa**
Dry	114.8	2331
heated and wet	49.2	1722
rate of variability	57%	26%

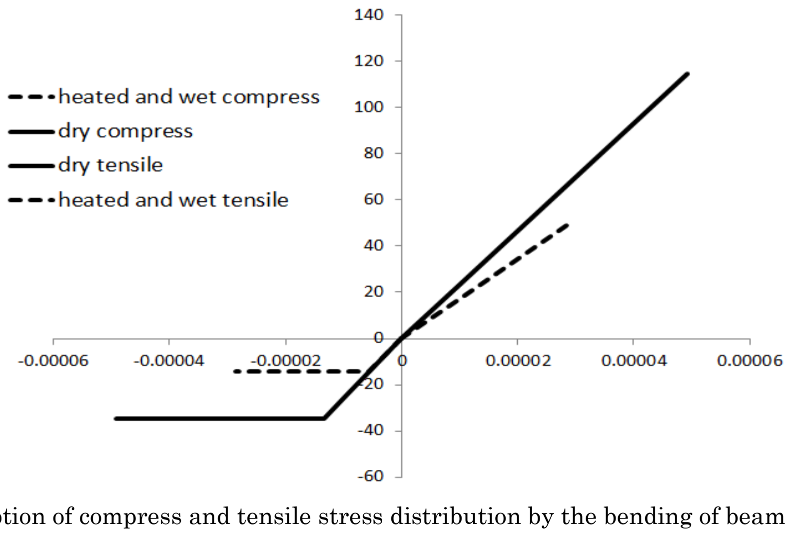

Figure 12. Assumption of compress and tensile stress distribution by the bending of beam theory

Figure 12 shows the assumption of compress and tensile stress distribution by the bending of beam theory from experimental results.

The decrease ratio of yield strength on compress is higher than that on tensile by condition of high temperature over FSP. Thus, it was thought that when bending moment was applied to thin wood, the neutral axis shifted to the outer tensile side with bending deformation, plastic deformation on inner compression side proceeded and consequently the thin wood could bend to a certain curvature without tensile failure.

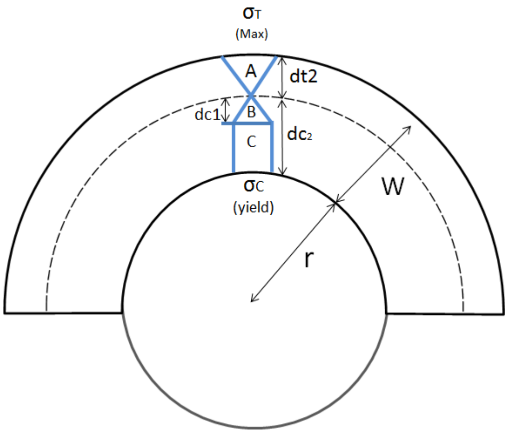

Figure 13. Relationship between curvature and thickness

Mechanical Model of Thin Wood Bending

In order to predict optimum curvature for thickness by changing of material property with high temperature over FSP condition, a mechanical model was established and numerically expected by data from tensile and compressive property with high temperature over FSP as shown **Table 1**.

Numerical Investigation of Bending Mechanism

A) Neutral axis in elasticity section

When thin wood plate (width: W) bends with certain curvature (r), two types of stress distributions by the bending moment of a thin plate will occur. One is a tensile stress, and the other is a compressive stress. The sum of the two stresses becomes theoretically equal as shown in **Figure 14**.

$$A=B \tag{1}$$

$$A=\frac{\sigma_T \cdot \delta_{T1}}{2} \quad B=\frac{\sigma_C \cdot \delta_{C1}}{2}$$
$$\sigma_T \cdot \delta_{T1}-\sigma_C \cdot \delta_{C1}=0 \tag{2}$$

The Neutral axis XP is decided in the same ratio between tensile and compress triangle areas in the elastic zone.

$$E_T \cdot \delta_{T1}=E_C \cdot \delta_{C1}$$
$$\delta_{T1}=\left(\frac{E_C}{E_T}\right)\delta_{C1} \tag{3}$$

From ultimate compressive stress (σ_{Tmax}) on table 1, tensile stress (σ_{Cy}) can be calculated. At this elastic condition, neutral axis is almost at the centre of the plate by comparison of tensile (δ_{T1}) and compressive (δ_{C1}) strains.

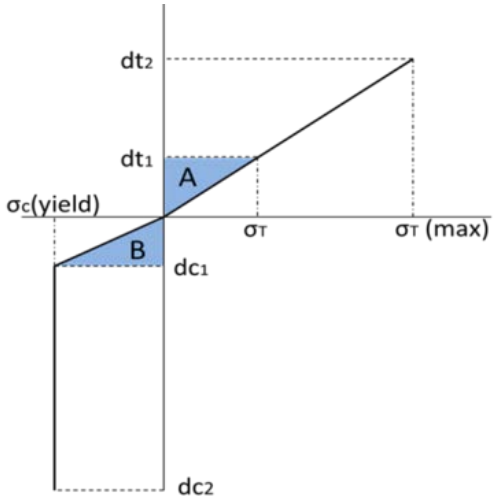

Figure 14. Elasticity zone

B) Neutral axis after yielding in compressive section

After reaching ultimate compressive stress (σ_{Tmax}), compressive stress is constant, otherwise tensile stress (σ_{Cy}) increases until maximum tensile stress (σ_{Tmax}) data as shown in **Figure 8**.

Thus, sums of tensile and compressive area becomes are theoretically equal as in equation (4).

$$A' = B + C$$

$$A' = \sigma_{Tmax} \cdot \frac{\delta_{T2}}{2} \quad B = \sigma_{Cy} \cdot \frac{\delta_{C1}}{2} \quad C = \sigma_{Cy} \cdot (\delta_{C2} - \delta_{C1}) \tag{4}$$

$$\delta_{C2} = \frac{\sigma_{Tmax} \cdot \delta_{T2} - \sigma_{Cy} \cdot \delta_{C1}}{2\sigma_{Cy} + \delta_{C1}} \tag{5}$$

$$\delta_{T2} = \frac{\sigma_{Tmax}}{E_T} \quad \delta_{C1} = \frac{\sigma_{Cy}}{E_C} \tag{6}$$

$$\delta_{C2} = \frac{\frac{(\sigma_{Tmax})^2}{E_T} - \frac{(\sigma_{Cy})^2}{E_C}}{\frac{2\sigma_{Cy} + \sigma_{Cy}}{E_C}} = \frac{(\sigma_{Tmax})^2 \cdot E_C + (\sigma_{Cy})^2 \cdot E_T}{E_T \cdot E_C \cdot 2\sigma_{Cy}} \tag{7}$$

From equation 6) and 7), equation 8) can be obtained by inputting factors of **Table 1**.

$$\delta_{C2} = 1.8\delta_{T2} \tag{8}$$

$$\delta_{C2} + \delta_{T2} = W \tag{9}$$

From equation 8) and 9)

$$\delta_{T2} = \frac{1}{2.8} W \tag{10}$$

Neutral axis can be expected by equation (10)

Finally, the neutral axis XP moves to the outside and the plastic deformation happens on the compression side until the tensile stress reaches the maximum value.

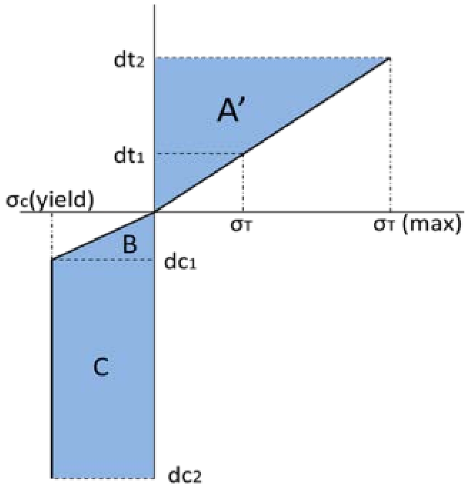

Figure 15. Plastic zone

Relationship between Curvature and Thickness

The maximum strain of the thin plate with high temperature over FSP is the correlation of the curvature (radius: *r*) and thickness. So, the maximum curvature can be calculated by Hooke's Law and Triangular scaling relationship.

$$\sigma_{Tmax} = E_T \cdot \frac{\delta_{T2}}{r+\delta_{C2}}$$
$$\sigma_{Tmax} \cdot r + \sigma_{Tmax} \cdot \delta_{C2} = E_T \cdot \delta_{T2} \quad (11)$$

Equation (11) is substituted for equation (12)

$$r = \frac{E_T - 1.8\sigma_{Tmax}}{2.8\sigma_{Tmax}} W \quad (12)$$

The maximum curvature of the thin wood bending is obtained by (13).

$$r = 11.8W \quad (13)$$

Experiment of Bending Curvature for Thickness

In order to exactly investigate the relationship between thickness and curvature without human variation, a thin wood bending test machine was devised, as shown in **Figure 16** and **Figure 17**. It can be applied to a constant distribution of load and displacement with almost the same mechanism as the thin wood bending process. It was conducted with 3 types of curvature for 3 kinds of thickness, which were 9 parameters in total. Success or failure was set as definition on each test. 3 tests were repeated at one parameter.

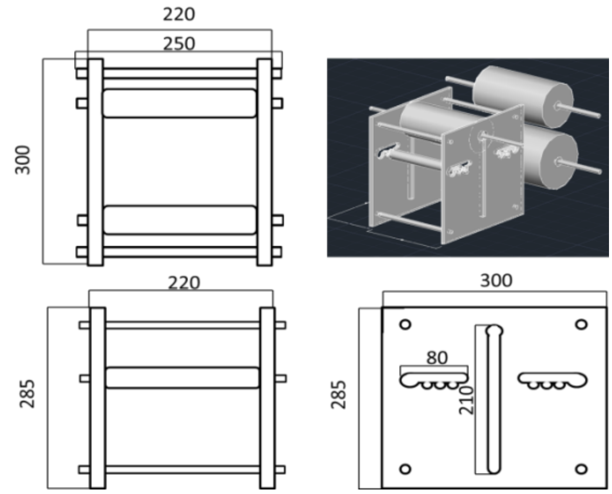

Figure 16. Draft for bending equipment (unit: mm)

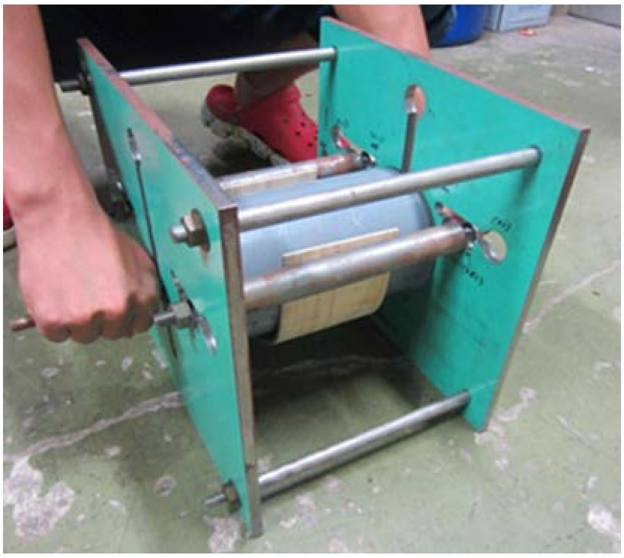
Figure 17. Apparatus of bending processing test

Figure 18 shows the experimental result of bending curvature for thickness. The success is marked with ○. It was concluded that comparison of results by mechanical model and experiment lead to a satisfactory bending processing condition.

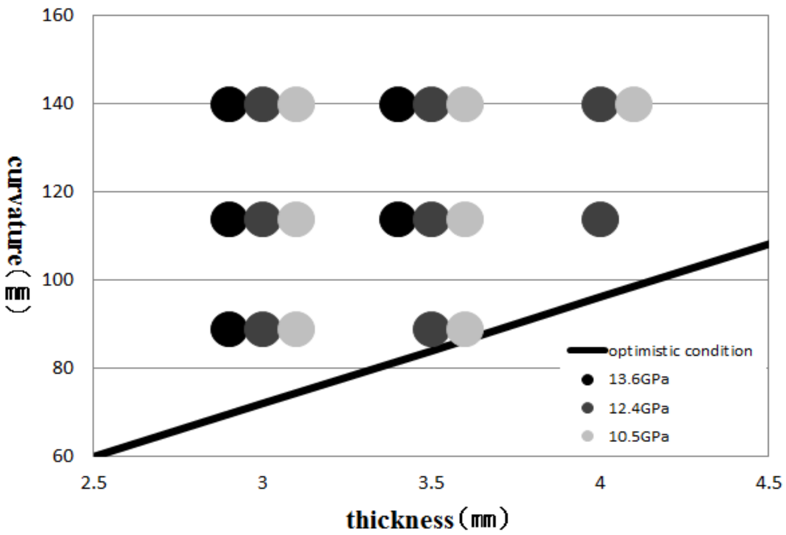

Figure 18. Experimental result of bending curvature for thickness

CONCLUSION

In order to introduce wood bending technology into technological education in the Junior High School, a wood bending process was established and wood bending teaching material was proposed and evaluated by teaching practice. Using a questionnaire, it was found that teaching materials using thin wood bending have high effectiveness in technology education. 85% students stated it was “interesting” and 73% students answered that they found thin wood bending helpful to understanding wooden structures.

On the other hand, bending mechanisms and optimum conditions of wood bending were verified in order to suggest an effective bending process as teaching material. The decreased ratio of yield strength on compress was higher than that on tensile by condition of higher temperature over FSP. The relationship between the thickness (2~5mm) of a thin plate and the optimal radius of curvature (44.5~70mm) was defined. Therefore, the comparison of results by mechanical model and experiment lead to a satisfactory bending processing condition.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Dr. Kiho Jung – Shizuoka University, Shizuoka, Japan.

Takahiro Shirai – Shizuoka University, Shizuoka, Japan.

When-shao Chang – University of Sheffield, Sheffield, England.

Yusuke Suzuki – Shimada Daiyon Elementary School, Shimada, Japan.

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