

## **A Study on Bentwood Furniture Design - Focus on Steam Bending Technique –**

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### **ABSTRACT**

At researching the history of furniture design, furniture based on the bentwood technique was often seen. There are different bending ways of wood. Among others the steam bending technique had been used since long time, but it's detailed method has been much less studied in Korea yet. The aim of the present study was to investigate the theoretical approach and making ways & process of the steam bending technique, and furthermore to utilize it for the works of the students majoring furniture design. This intends that the steam bending technique will be widely distributed by doing a mock up and it will be diversely used for development of more different furniture designs.

**Key words:** Steam, Bending, Steam Box, Lamination, Bent wood Furniture.

### **1. INTRODUCTION**

#### **1-1 Purpose**

The beginning of the bent wood technique goes back to the 18<sup>th</sup> century. It was derived from the technique of production for vessel and wheel of carriage. The start of the applied bent wood technique to the furniture was Windsor Chair in the early 1730s. By applying and using the bent wood to furniture the efficiency and structure of wood can be improved and it positively influences to economical aspect of wood. Bent wood technique contributes to beautiful expression of the curved wood and different design sills thanks to natural carving methods. The technique of bent wood are classified in Milling Solid Stock (direct woodcarving way), Plate Bending, Kerf Bending, Lamination Bending, Steam Bending etc. This study is intended to research the bent wood technique through Steam, and to present the related works.

#### **1-2 Scope and Method**

The bent wood technique used since 18<sup>th</sup> century and the historical meaning of the to furniture applied bent wood technique were here investigated. Among others Steam Bending technique based on Bent Solid and Laminated wood lies in middle point of the present study. Basic material/preparation and wood for Steam Bending working are introduced, and furniture design focusing on steam bending is presented on the based of the production procedure.

### **2. Study of Bent Wood furniture**

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Received for publication: Mar 3, 2009 ; Reviewed: Apr 5, 2009 ; Accepted: May 15, 2009.

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## 2-1 Definition

Bent Wood means the bent/carved wood literally. It means namely the formatively transformed type of wood by an artificial processing of the slight sawing (Han. 2004). Furthermore it means the curved transformation of the wood to represent the beauty of curve and the formative art of wood.

## 2-2 Origin of Bentwood Furniture

The starting point of Bent Wood derived from the production of wooden-vessel. Around B.C. 3000 rescue boat/vessel was presented in Egypt and facts of the vessel production were showed in Rome, Phoenicia and Greece etc. in many countries already in the period B.C. (<http://kin.naver.com>). Such Bent Wood technique had been started to be applied to furniture in early 1730s in Windsor province England by Windsor Chair as the first. The 18<sup>th</sup> century was the period of prosperity for the furniture making in Great Britain. The accumulation of wealth of the civilian besides the widespread architectural activities at this time had created huge demand for new type of furniture on the basis of the high level of furniture manufacturers. Windsor Chair imitated by the archetype of Britain was in style & mode in 18<sup>th</sup> Century in America and it remained also in quality and grade despite of mass production at cheap price (Lee. 1999). The used wood sorts were ash, yew and several fruit woods. For the street stalls pine and birch were used and for bar or table beech, birch, ash and as bent wood for shelves maple, ash, quercus serrata and birch etc. Michael Thonet of the mid-18<sup>th</sup> century has been manufactured according to the material, production and construction at that time up to now (Han. 2004).

## 2-3 Works of Bent Wood and Laminated Wood with time



Fig 1. Chair(1808)  
Samuel Gragg  
Bent Ash & Hickory



Fig 2. Model No.14  
(1796 ~ 1871)  
Michael Thonet  
Bent Solid Beech.



Fig 3. Chair for the  
Cafe Museum(1898)  
Adolf Loos  
Stained, Bent Beech.



Fig 4. No.670,c(1908)  
Josef Hoffmann  
Stained, Bent solid wood  
and laminated



Fig 5. Model No.41(1930)  
Alvar Aalto  
Bent laminated and  
solid birch.

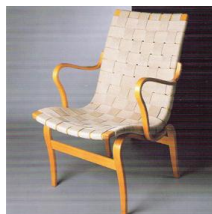


Fig 6. Eva chair(1934)  
Bruno Mathsson  
Bent plywood and  
solid birch.



Fig 7. Cherne(1957)  
Paul Goldman  
Walnut-faced moulded  
plywood.



Fig 8. Powerpla (1990)  
Frank O. Gehry  
Bent and  
Woven laminated wood.

The Industrial Revolution of 18<sup>th</sup> century in England and development of technology accordingly had made a new mode in U.S. furniture market. Samuel Gragg obtained a patent of bent

wood chair made from collected plywood. Michael Thonet made a research regarding light and firm chairs at reasonable price in 1830, and made a regency-typed chair in 1840. After then he fully mastered a technique of bent wood chair made from steamed and accordingly bent beech. This Bent Wood technique of Michael Thonet had brought a lot of changes in furniture form. It had a big effect on Otto Koloman Wagner, Adolf Loos and Josef Hoffman, and the molded chair made from plywood of Gerrit Tomas in De Still group and the bent wood chair made from laminated plastic of Marcel Breuer in Bauhaus. Bent Wood technique has been developed by Alvar Aalto still more (Han. 2004)

### **3. Study on Steam Bending Technique**

#### **3-1 Definition**

Inside of fiber of wood there is natural adhesives named as Lignin and they are stuck to each other. If wood is steamed at 80 °C ~ 100 °C, Lignin inside of fiber of wood gets temporary loose. Exactly at this moment the outside of wood grows longer without any tears, the inside of wood is compressed and it can be instantly bent (Lon. 2007). After getting cold the status of wood remains bent. Such bent wood technique based on steam bending is usually used for furniture legs / cabrioles. This improves the strength of furniture legs and expresses a beautiful & natural wood grain. Furthermore it contributes to economical aspect of furniture thanks to a lightweight and material reduction. Steamed way rather than dry heat is more efficient.

#### **3-2 Merits and Demerits of Steam Bending**

##### **1) Merits**

- Tendency of lightweight and material & cost reduction contribute to the economical efficiency.
- Wood is more strong at bending than at cutting curved.
- Different curves are available according to the desired styles.
- The grain of wood can be naturally expressed.

##### **2) Demerits**

- Preparation and procedure of production are complicated.
- Failure occurs often due to damage of wood and the desired shape is not always made.
- Due to steam at high temperature danger of burn is exposed.
- Short working time needs a very skilled technique.

#### **3-3 Steam Bending Wood**

##### **3-3-1 Woods available for Steam Bending**

Only broad-leaved trees are available and the needle leaf trees not possible (Andy. 2005). They are hard and strong enough, and have unique color of wood. Different colors and grains of wood are here the subjects.

##### **3-3-2 Selection of wood for Steam Bending**

The important issue at steam bending is the success rate of bending. Namely damage rate of wood has to be low at giving pressure on it (Lon. 2007). The choice of wood plays an important role accordingly. The most used sorts of wood for steam bending in the country are White Oak, Red Oak, Walnut, Hickory, Beech, Birch, Ash and Maple etc. Woods having success rate usually over than 70 % are suitable.

Table 1. Bending success rate and minimum radius

(The Taunton Press. 1990)(Wee,2005)

Sorts of wood	Success Rate(%)	Minimum Radius (mm)		Sorts of wood	Success Rate(%)	Minimum Radius (mm)	
		with mould	without mould			with mould	without mould
Hackberry	94	*	*	White Oak	91	25	290
Red Oak	86	25	290	Walnut	78	25	280
Hickory	76	46	380	Beech	75	38	330
Birch	72	76	430	Ash	67	110	330
Maple	57	*	*	Chestnut	56	460	840
Bass Wood	2	*	*				

'\*': no data

### 3-3-3 Lumber for Steam Bending

The best wood for steam bending is that the annual ring of the section lies vertically with the bending side (Lon. 2007). Wood grain of profile is recommended to be horizontal with the upper side of wood. Wood with slant lines is easily broken by any pressure. The suitable thickness for steam bending is less than 25mm. In case of thicker than 25mm, more pressure is given, so failure occurs very probably. Therefore the wood for steam bending is expected to be purchased specially from any lumbermill.



Fig. 9. Lumber section.

### 3-4 Preparation for Steam Bending

#### 3-4-1 Lumber

- 1) Green wood is recommended. Especially the dried wood in kiln is very difficult for steam bending. If the naturally dried wood is the case, it has to be dipped into water at least 24 hour before bending (Lon. 2007). The reason for that is to enhance moisture inside of wood and to spread heat into the wood evenly.
- 2) The maximum thickness of wood for bending through steam is 25mm and the time is 1 hour (Lon. 2007). The 12 mm wood e.g. is steamed during 30 minutes.
- 3) The annual ring of wood is expected to be horizontal with the bending direction and straight-grained wood of profile is recommended. In case of the slant-grained wood, proportion of slope has to be more 1:15 (length: width)(Lon. 2007).
- 4) The wood for steaming bending needs to have ample measure. If the desired result appears, then exact measurement has to be made by saw and plane etc.
- 5) The surface of wood has to be smoothly and cleanly sanded. It prevents the surface from crack and is helpful for a success of bending.
- 6) Avoid the knotty woods.

#### 3-4-2 Steam Box

- 1) For Material of steam box cedar tree is recommended thanks to its moisture-resistant characteristic.
- 2) The size of steam box needs to be made a little bigger at width and length than the wood to be bent. In case of the too much bigger size however, time and energy are wasted to make unnecessary steam. In particular, divide the inside space of steam box in 3 parts (top, middle and bottom part) by wood-stick. The temperature gap between top and bottom part is more than 10°C. Therefore the

reserved woods, in case of that there are many woods for bending, can be put in bottom part and the wood rightly to be bent in top part where the temperature is be evenly spread. It is effective to make 2 steam caps, if steam box has wide width and/or longer length. (Lon. 2007)

- 3) Inlet of steam would be better made in bottom and middle of steam box. In case of wide and/or long steam box, more than 2 inlets are effective.
- 4) At producing of steam box with real wood, the gap with 2~3 mm is recommended. The swell of wood due to high steam fills up this gap.
- 5) If steam box would be made of veneer, it is necessary to install it leant to one side. Make a small hole as an outlet for steam on the upper part of steam box and a waterway on the bottom slant of steam box.
- 6) Important at making steam box is easy to open. The opening & shutting like up & down motion would be convenient.
- 7) For connection between the woods of steam box, stainless screw is recommended.
- 8) For the reason that steam box has to be installed on the 1 M height raised on the ground, strong-constructed pedestal for steam box needs to be made.
- 9) In winter season e.g. when the internal temperature of steam box is difficultly keep over than 95 °C because of external influence of temperature, it would be a good idea to use lagging material on the surface of steam box.

### 3-4-3 Steam Hose

Steam hose plays a important role as a steam transfer by connecting steamer and steam box. For the material of steam hose accordingly is hose for radiator suitable, because it is heat resistant and heat-retaining at the same time. The best case to use steam efficiently is that steam hose is vertically connected between the steamer and inlet of steam box as short as possible.

### 3-4-4 Steamer

As a steamer the zinc galvanized material is suitable. The capacity of steamer has to be over than 20 l. Install a water gage and check always it and supplement the water.

### 3-4-5 Burner

For steam bending process, it is important to produce sufficient steam constantly. So, the burner should have strong heating power. At small scale working like modeling portable burner with butane gas is available.

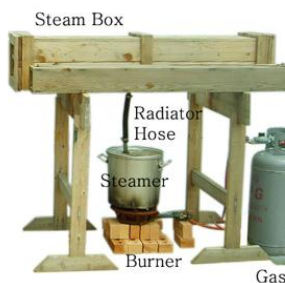


Fig. 10. Steam Box.



Fig. 11. Water Tank.



Fig. 12. Steam Bending Form.

### 3-4-6 Water Tank

In case of dried wood, it should be in water tank 24 hours prior to working, to keep sufficient

moisture. PVC pipe would be helpful to use any long wood longer than 1 M. After cutting the top of pipe with saw and put the wood into it. Both edges of pipe should be covered by the PVC-only cap.

### 3-4-7 Steam Bending Form

- 1) Bending Form is a mold to bend the wood according to the desired shape. The width of bending form has to be made a little bit wider than the wood to be bent, the length shorter.
- 2) For the material for bending form plywood with having high compressive strength is good. Real wood is not suitable due to transformation through steam, and MDF is not strong enough at compression.
- 3) the remarkable point at making bending form is that it should be produced 20~ 30 % smaller than the wanted angle(or the diameter of curved line)(Lon. 2007). The bent result shows “Spring Back” phenomenon during being dried.
- 4) In order to fix up clamp in bending form, the hole has to be made. The more angle of bending, the closer the gaps should be placed. In case of lineal line, the gaps between holes do not have to be so close. Consider always the clamping time !
- 5) In case of bending for the long wood more than 1 M, it is convenient to install any strong supporting maintenance in advance at the both ends of bending form. If the one end of the wood would be bent, after having fixed the other end of the wood, the working procedure could be done by one person.
- 6) In case of Lamination Steam Bending, the contact area between the edge of steam form and the wood to be bent should be taped. It could prevent that bending form and wood stick to each other due to the overflowed adhesive.

### 3-4-8 Clamp

Clamp is C-Clamp being good at compressing force. Steam bending has different duration time and this time is very important, so, be sure of sufficient clamps before starting working. The first of clamping is to fix the middle of the wood to be bent and then to process both sides.

### 3-4-9 Compression Strap

If strong pressure would be given at bending, the fiber of outside of the wood is raised and furthermore in case of stronger power, the wood is torn and the bending fails. To supplement this problem the compression strap is used in the outside of the wood.

At this moment compression strap prevents the tensioned fiber from torn. For the material of strap stainless steel with 1 mm thickness is recommended for the reason that it easily returns to the first condition after bending working. In order to

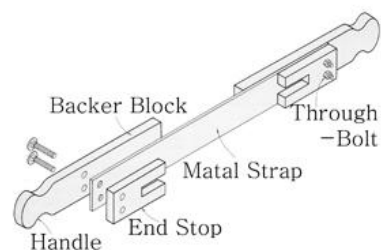


Fig. 13. Compression Strap and Handles.

prevent the cases that the ends of wood grow longer or split out curved, the end stop made of wood or metal angle may be installed on the ends of strap like the above picture.

### 3-4-10 Fireproof Gloves

Burn hazard could often occur, when the wood is taken out of steam box after being steamed at high temperature. Pay attention to bring face not to be close to steam and to wear absolutely the fireproof gloves.

### 3-5 Procedure of Steam Bending

- 1) Development of design : the radius of the curved line is different at designing furniture according to the thickness and sorts of woods, but the design with hardwood more than 25mm thickness the minimum radius more than 100mm has the best success rate.
- 2) Production of bending form : bending form is made of plywood 20 ~ 30 % smaller than the radius of the final result (Lon. 2007).
- 3) Selection and Cut of the wood : Sort of wood is chosen first. Then it should be cut, when the annual ring parallels the bending direction and the profile of wood shows lineal wood grain.

Table 2. Lumber Selection

Wood	Width of wood	Length of wood	Thickness of wood
Hardwood in consideration of color & grain of wood	5~10 mm wider than the final result	200 ~300 mm longer than the final result	1 mm thicker than the final result

- 4) Wood in water : wood for steaming bending is usual green wood. But in case of dried wood, it must be soaked in water tank 24 hours long before working.
- 5) Preparation for bending : prior to steam bending cut & moisture content of wood, burner, available gas & water, hose, steam box, bending form, clamp and finally fireproof gloves should be checked. Then water is steamed.
- 6) Creation of steam : if water would be sufficient heated and if steam is full inside of the box, the wood is put into the top part of the box.
- 7) Bending procedure : the wood pulled out of the box should be fixed in bending form within as quick as possible.
- 8) Drying : after drying of the wood, steam form and strap have to be separated and fixed by clamp & rubber and keep 24 at least 24 hours long for a full drying, against Spring Back phenomenon.
- 9) Finishing : for the wanted thickness, width and length, additional process by plane is followed for a completed finishing.

### 3-6 Lamination Steam Bending

If the thickness is more than 25mm or high pressure is needed at bending, Lamination bending is useful. The explanation of the picture shows the case of lamination bending of the 6 storied layers with 8mm thickness of the wood.



Fig. 14. Lumber Cutting.

#### 3-6-1 Work Procedure of Lamination Steam Bending

- 1) After marking “Δ” on the wood like the picture, saw the wood in consideration of the annual ring and grain.
- 2) Keep the wood in water 8 hours long, in case of the dried wood with 8 mm thickness.(in case of green wood this step is omitted.)
- 3) Production of steam box is necessary and the taping in contact part between the wood and strap is necessary, too.
- 4) Let 6 woods stand evenly in steam box according to the mark “Δ” in order and steam 20 minutes.
- 5) Pull out the wood in order according to the mark “Δ” and make a strap and fix it into steam form as quick as possible.
- 6) Once the wood is dried, separate it from the steam form and strap, and fix it by help of the clamp & rubber and let it dried completely, so that Spring Back phenomenon does not happen.

- 7) After the wood is completely dried, put epoxy lightly on that.
- 8) Make a strap again and make a clamping in steam form like the above mentioned.
- 9) Keep at least 24 hours long like that and then separate the wood from steam form and complete finally the bending.
- 10) Cut the wood according to the desired thickness and dimension.

### 3-6-2 Comparison between Steam Bending and Lamination Steam Bending

Wood	Steam Bending	Lamination Steam Bending
	Hard Wood	Hard Wood
Story of wood	Single panel less 25mm	More than 3 storied wood less than 25mm
Work convenience	good	difficult / trouble
Durability	weaker than Lamination Steam Bending	stronger than Steam Bending
Spring Back	shown	little chance
Working time	short	long
Adhesive	without it, texture by texture	with epoxy
Carving	natural	unnatural
Environmental	friendly	harmful ingredient added

## 4. Study on Furniture Design based on Steam Bending

Fig. 15. BoheRian (2007).

Lee, Soo-Hee (Dept. of Furniture Design Hyupsung Univ.)  
 Red Oak. 650×650×300. 300×300×200. 250×250×200(mm)

Table reminding of legs of the mollusk and legs of stool were treated by Steam Bending. It offers user interest and comfort and expresses soft image. Against Spring Back top & bottom panel and legs were treated by Dovetail Joint, and Lamination Steam Bending made by 3 layers with 6 mm thickness.



Fig. 16. Cradle from the cradle to the grave (2007).

Jang, Dong-Wook (Dept. of Furniture Design Hyupsung Univ.)  
 White Oak, Walnut, Leather. 1800×600×300(mm)

Cradle and runner part are processed by Steam Bending. Design concept here was focused on safety for baby and gentle-rocking motion. For the connected part between cradle & runner, cowhide was selected for soft rocking.



Fig. 17. Blossom Shine (2007).

Baek, Yul-Lee (Dept. of Furniture Design Hyupsung Univ.)  
 Red Oak, Walnut. 460×1100×860, 450×280×510(mm)

Lamination Steam Bending is showed in legs of console and stool. The motive of flower bud was positively expressed, and design was developed in visual tension in consideration of safety. Both ends of bending were composed of shiplaps against any transformation of curved line.





Fig. 18. Red Wine (2007).

Kim, Hyun-Min (Dept. of Furniture Design Hyupsung Univ.)  
Red Oak, Ebony, Leather. 600×600×850, 340×340×550(mm)

Table & legs of stool were treated by steam bending. Motive of the wine glass was applied and designed. Lamination Steam Bending and Wedge were used to prevent Spring Back.



Fig. 19. A Gift for You (2007).

Kim, Su-Jung (Dept. of Furniture Design Hyupsung Univ.)  
Ash, Maple, Walnut. 440×700×330(mm)

Lamp shaped from giving present with utmost sincerity. The arms holding present were treated by Steam Bending. The half circle was bent and lamp part made by shiplap, and box part by wood sticks.



Fig 20. 連理枝 (2008)

Park, Ha-Na (Dept. of Furniture Design Hyupsung Univ.)  
Ash, Walnut, Ebony. 800×250×1700(mm)

Shelf presents leaves hanging on branch of tree. Pillars imaged from branch of tree were treated by Lamination Steam Bending, and connected symmetrically. To prevent Spring Back bars in bottom parts were treated by Dovetail Joint, and pillars & shelves by wedge.



Fig 21. Fortune Furniture

Kim, Eun-Eun (Dept. of Furniture Design Hyupsung Univ.)  
Red Oak, Walnut. 1400×1010×300(mm)

Console-typed drawer presenting a lucky bag. Both sides of drawer were divided in 2 parts with 18mm thickness and 140mm width respectively and treated by Steam Bending, and 2 bent woods were connected. In the contact area between the bent part and panel, Finger Joint was used.



## 5. Conclusions

Furniture based on the bent wood technique is a widely distributed and used production technique of furniture since the middle of the 18<sup>th</sup> century. Among the diverse ways of the bent wood, the bent wood technique based on the steam has been less introduced in Korea. The lack of the theoretically systemized data for complicated preparation and difficult production procedure has made the students majoring furniture design, artists making wooden furniture and managers running carpentry school etc. inconvenient. Hereupon in the present study theoretical summary regarding Steam Bending and right production procedure resulted from many times failures were researched and analyzed, so that the most of people could make a steam bending work.

For the selection of the wood sorts for steam bending, hardwood is recommended like Oak and

Beech, and absolutely green wood should be used and/or be soaked in water 24 hours to keep the high percentage of moisture content in case of the dried wood. Steam time is usually 1 hour for the 25 mm thickness of the wood and it can be adjusted according to the any thickness. There are many preparations for Steam Bending work. Water Tank, Steam Box, Steamer, Hose, Burner, Gas, Bending Form, Clamp, Compression Strap etc. should be checked prior to main working, in particular checking of water gage is absolutely necessary. Bending Form plays an important role at Steam Bending. It has to be firmly made at the size of 15~20 % smaller than the desired curve line. The pulled wood out of steam box should be fixed in Bending Form as quick as possible. Then after 24 hours drying process in the air naturally, it should be fixed by rubber band to prevent the Spring Back phenomenon.

On the basis of this study Steam Bending Technique which had been much less approached was researched through the graduate works of the student majoring furniture design and their different designing and high-level working processes. Steam Bending is the best technique to be utilized not only for the mass-produced furniture, also for artists of woodworking and private carpentry school. The aim of the present study is therefore to use and utilize the Steam Bending technique as widely as possible.

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