Solid Wood Bending

1 Introduction

Solid wood bending is a well known production method. In former times, bended wood was mainly used for planking hulls of ships. In the middle of the 19th century, the German carpenter Michael Thonet developed a method for solid wood bending. He noticed that wood while bending always splitted on the outermost side. He stopped the breaking by supporting the wood by a metal strap on the convex side. Therefore, the wood bending method by using a strap is also called the Thonet Method.

Since those days, the major field for wood bending is chair production. Due to good material properties, bentwood was also used in aircraft production (mainly until 1945) and it is still used for different types of sport sledges.

2 Stages of the process

During the solid wood bending, three major stages have to be passed: softening - bending - stabilising, figure 1.

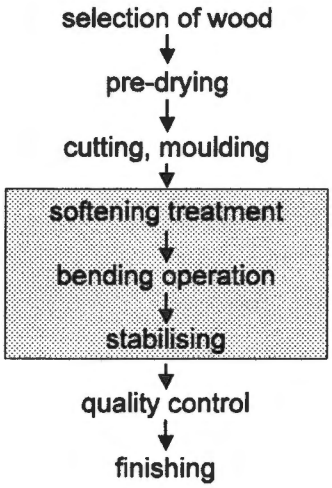

Figure 1: Stages of the wood bending process

3 Softening treatment

While softening, the wood is heated up to a temperature of at least 80°C. In addition, wood has to have a certain moisture content. Together, the influence of moisture and temperature softens the wood and makes it flexible for bending, figure 2.

It is most important, that wood is softened properly. The most convenient way to soften wood is to expose it to a steam atmosphere. The time to expose bentwood to steam for the softening treatment refers to the thickness of the material. A practical rule for Beech (*fagus sylvatica l.*, a very common bentwood in Europe) says that the exposure time is about one to two times the thickness of the workpiece. That means, for a piece of A = 30 • 40 mm² the required time

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in the steaming unit ranges between 30 min and 60 min (thickness: 30mm).

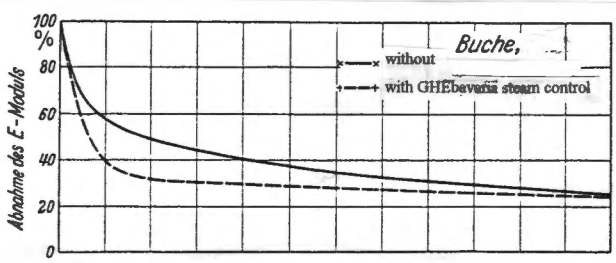

Figure 2: Change of rigidty while softened with steam

The moisture content of the bentwood after steam softening depends on the density and on the moisture content before the softening treatment. There is a natural range in density for every kind of wood. Wood with lower density can usually absorb more water and therefore has a higher increase in moisture content due to a softening treatment than wood with a higher density, figure 3. The time for exposing wood to a steam softening atmosphere has to be found individually for each species of wood.

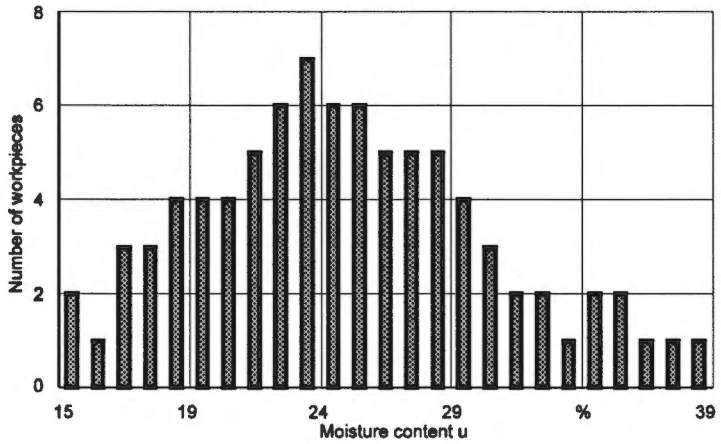

Figure 3: Average moisture content after softening treatment in steam

By the same, wood should not be exposed too long to a softening treatment and it should not be made wet, too. The longer wood is exposed to a steam atmosphere, the more it will change it's colour to dark. The more moist it will contain due to the softening treatment, the more effort has to be taken to dry the workpiece after the bending process. This effects costs and time. Usually, a moisture content ranging from 20% to 25% can be considered as good for bending.

4 Bending procedure

During the bending procedure, the workpiece gets its shape. The central problem while bending wood (in this stage, a proper softening will be assumed) is that wood usually does not allow to be expanded due to bending tension on it's outermost side, figure 4. But because of the cellular structure of wood, compression load can be absorbed easily by deformation which causes simultaneously an increase in density. Therefore wood can be bent if it is supported by a metal strap on the convex (= outermost) side. And usually there is no remarkable change in

profile while compressing the wood in a bending process.

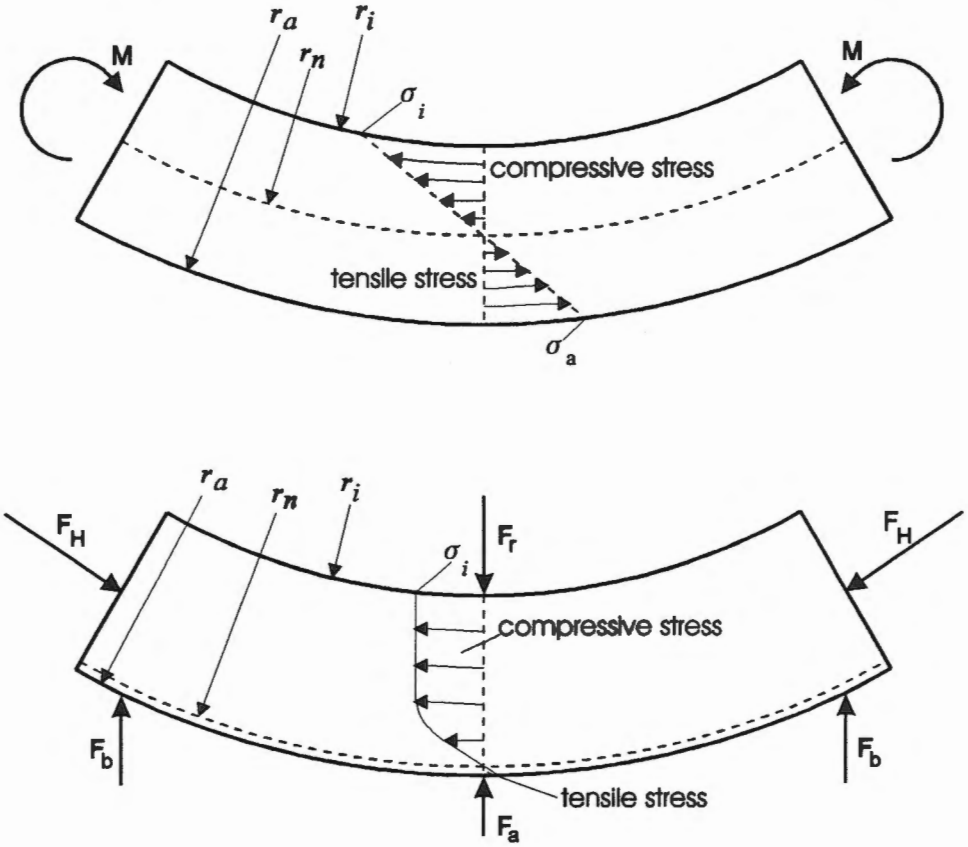

Figure 4: Compressive and tensile stress for general bending (above) and wood bending (below).

The metal strap covers almost the total amount of the tension load, which occur during the bending process. But it is very important, that this strap is perfectly fitting to the workpiece before starting the bending process. Any tolerances between this strap and the workpiece result in damages of the bentwood (see also fig. 9 & 10).

Depending on the type of machine and the kind of geometry, the average time for bending is between 5s and 20s.

5 Stabilising

After bending, for a certain time wood is still in a viscoelastic state. That means bended wood will spring back when released right after bending. To avoid this spring back, the workpiece has to be fixed to its position until internal bending forces have settled. This settlement is called stress relaxation. Then the clamping can be released. From now on, the workpiece will stay in shape with good accuracy.

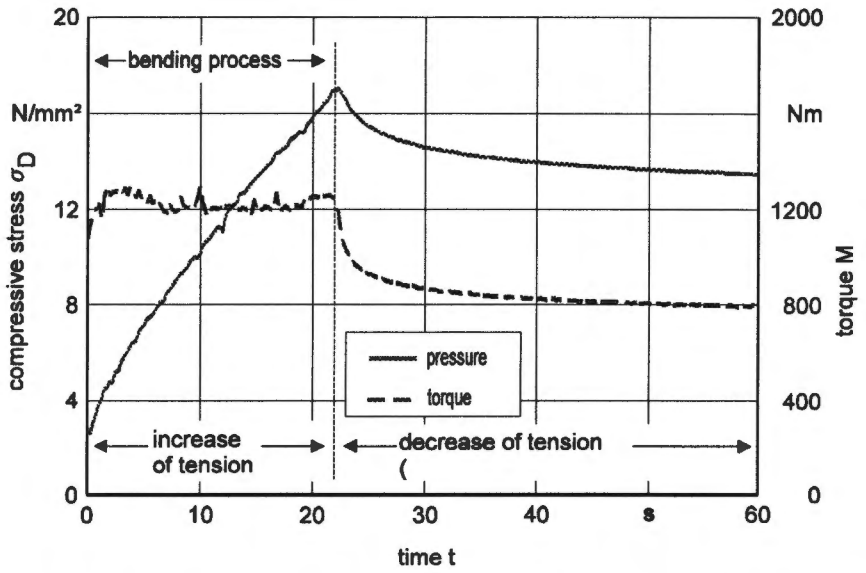

Figure 5: Typical behaviour of torque and end pressure during and after bending

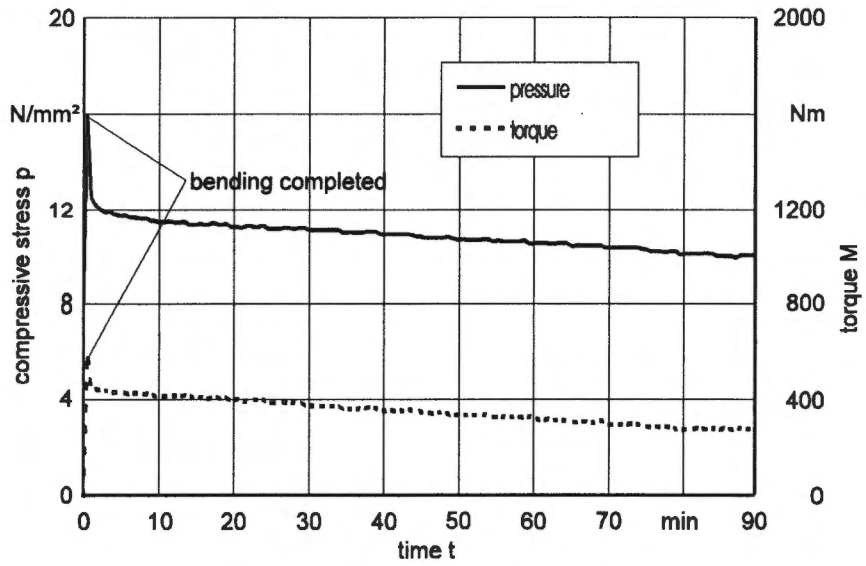

Figure 6: Decrease of reaction forces of wood after a bending operation

6 Boundary conditions

6.1 Selection of wood

Not every wood species can be used for bending operations. If the bending properties of a certain species are not exactly known, tests have to be made first. In general however, it can be said that most of hardwood species are considered to have more or less good bending properties.

The mechanical properties range widely in every species. Tests have shown that even in one stem, the modulus of rigidty varies more than 40%. Not every piece of a stem can be used for bending. Because of the high deformations, only homogenous grown pieces of excellent

quality should be used for bending. For example, a knot inside a board causes a high local increase in density. Therefore it is recommended to use only boards free from knots for bending.

6.2 Bending damages

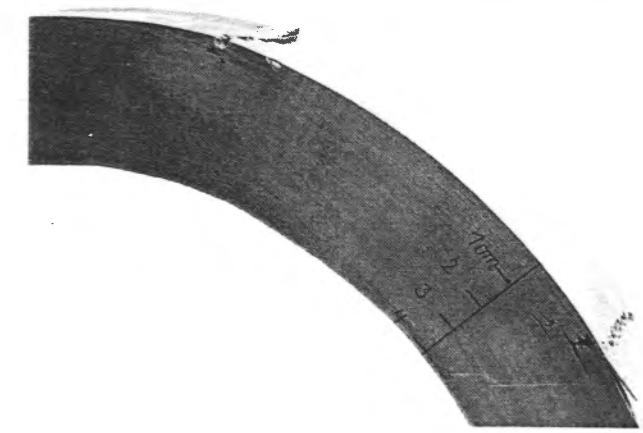

Figure 7: Bending damage: Transversal break

The bentwood usually breaks transversally, if the bending strap was not fitting tight on the bentwood. However, the damage may appear in case that the centre pressure is too low, too.

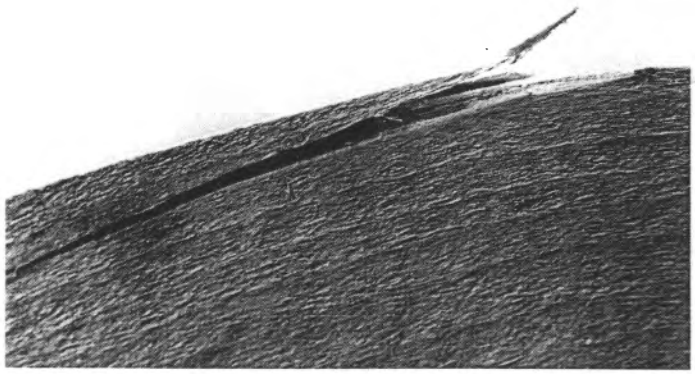

Figure 8: Bending damage: Split off

Like the transversal break in figure 7, this damage is a sign that the supporting strap has not fitted to the bentwood. The difference between figure 7 and 8 is the position of the cells. Splits and breaks also appear, if the bentwood was not supported long enough by the strap.

Broken cells as to be seen in figure 9 are usually a typical sign of a poor softening. As soon as the softening treatment is improved, these damages normally disappear.

If a bentwood gets folded as in figure 10, there can be two reasons for. One possibility is the centre pressure is too low. Then the inner side may be folded, where on the outer side of the bending, breaks can appear. The other possibility is, that there is a knot or any other

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inhomogenous zone inside the material which causes the fold.

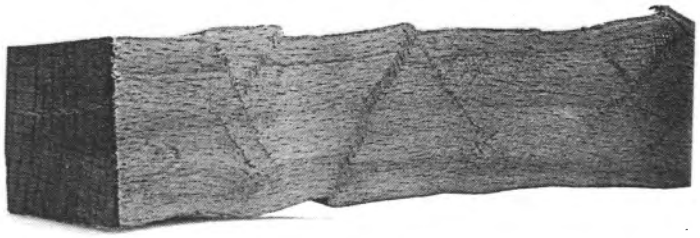

Figure 9: Bending damage: Broken cells

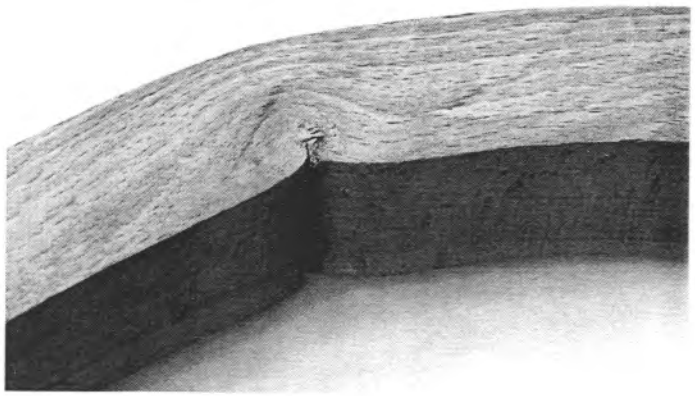

Figure 10: Bending damage: Folding

7 Bending equipment

7.1 Softening treatment

It is proven, that the most efficient softening is the steam softening. For a high efficiency in softening treatment, a steam generator and a steaming tank is recommended. As it is known, the steam for softening treatment has to be taken care of in a very sensitive way. GHEbavaria designs and supplies all installations from the steam generator to the steaming tanks.

Solutions are generally customised to specific needs, because it was found out that standard solutions do not have the same efficiency.

7.2 Bending machines

There are three basic types of bending machines. The most common machine is the universal type, which is convenient for most bending operations. The bending angle is usually up to

200°, but can be limited by the dimensions of the workpiece. The bending of a U shape with these types takes about 20 s. There are two types of machines: The machine for symmetrical bendings is STUZAMA I (one electrical drive), where the machine for symmetrical and non-symmetrical operations is STUZAMA II (two drives). Because of the two drives, the STUZAMA II is more powerful, too. This results in a better capability for bending thicker workpieces.

According to the customers needs, these machines come with manual or automatic features for centre pressing and / or longitudinal clamping. This machine is driven electrically and needs compressed air for the centre pressing. For heavy duty operations, this machine can also be equipped with hydraulically drives for all functions (STUZAMA H). Depending on the geometry of the workpiece and on the automatisation equipment, between one and three cycles per minute can be achieved. Figure 11 shows a GHE bavaria wood bending machine, type STUZAMA.

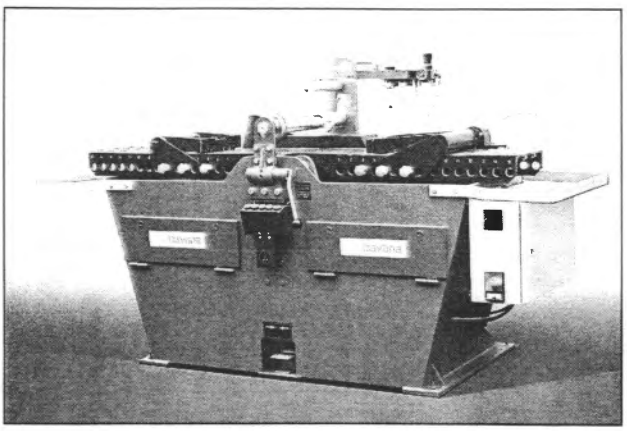

Figure 11: Universal wood bending machine for chair frames and open shapes STUZAMA.

If the emphasis for bending speed has to be made, the STUZAMA VP can be the first choice. This machine operates faster than the standard STUZAMA , but is limited to a bending angle of about 90° (depending on the geometry of the workpiece), figure 12.

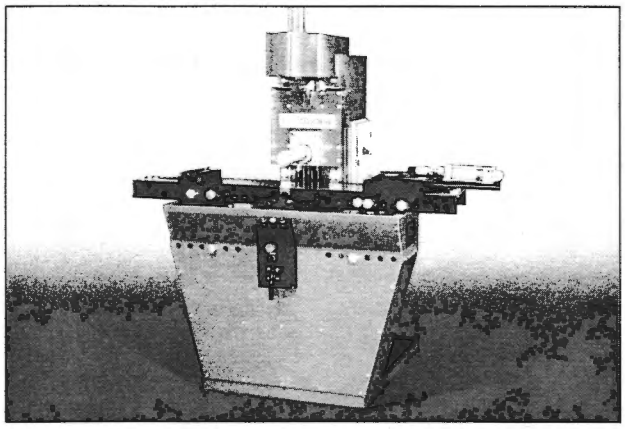

Figure 12: Fast operating bending machine for chair backs and bendings up to 90° angle STUZAMA VP

Hangers for clothes or chair parts like backrests and chair legs can be suitable for that type of machine. Depending on the geometry of the workpiece, three to four bending circles can be achieved.

Not only open bends can be formed with a wood bending machine. Even circular or spiral bends can be bent on a GHEbavaria wood bending machine, type RUBIMA. Depending on the geometry of the particular workpiece, this machine operates with a bending angle up to approximately 450°, figure 13.

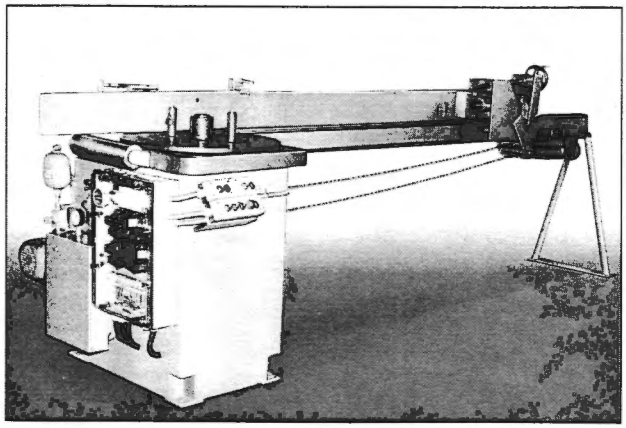

Figure 13: Universal bending machine for closed circles RUBIMA

7.3 Stabilising equipment

For stabilising it is very common to use standard drying equipment. The only difference is, that wood should be fixed, to ensure that the bended shape remains during and after the stabilising process. Besides that, a stabilising line can be used between the bending machine and the drying chamber. This line carries the bended wood together with its strap and its clamp from the bending machine to a second place, where clamp and strap are released. For not all internal tensions have settled right then, the bentwood workepieces are put into a frame on a carrier an then brought into the drying chamber, where as a second carrier takes the straps and the clamps back to the bending place, figure 14.

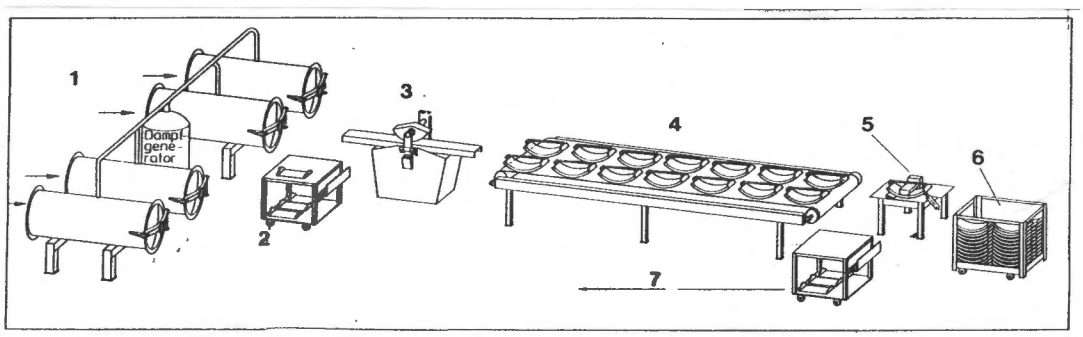

Figure 14: Conceptional lay out of a complete bending line: 1 *steam generator with steam tanks*; 2 *mobile working desk*; 3 *bending machine*; 4 *stabilising line*; 5 *clamp release device*; 6 *frame carrier for drying chamber*; 7 *carrier going back.*

A stabilising line improves the material flow and decreases the process time. By the same time costs for drying energy and straps / clamps are reduced.

7.4 Additional equipment

Besides the softening / steaming unit, several equipment is needed for bending wood. First of all, this is are a mould, a strap and a clamp to fix the wood to the strap after bending. Figure 15 shows this equipment.

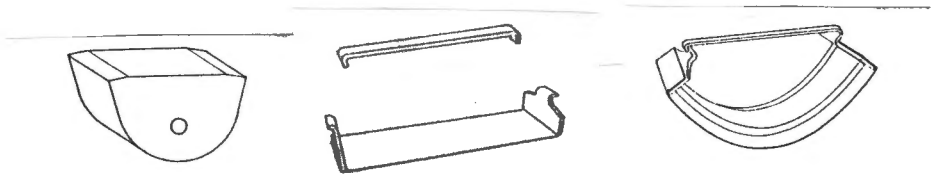

Figure 15: Bending equipment: mould, strap (bending plate), clamp and bended workpiece

8 Wood bending in practical

Before softening and bending the wood, the material should be selected. No knots should be in the centre of the bending. It has been proven that wood achieves better bending results when first moulded to a smooth surface. Then it has to be cut carefully to ensure that the length of the workpiece is not too short.

The next step is the softening treatment. The time for softening is related to the thickness of the workpiece. Usually, it can be said that twice the thickness of a board in mm is the maximum required time for the softening process in min (Beech). That means, a 30mm thick board of Beech can usually be considered to be soft and ready for bending after about 40 to 50 min. As soon as the workpiece is soft, it can be bent.

To bend the wood, it has to be put into a strap. The strap has to fit tight to the edges of the wood. There can be two or more workpieces inside a strap, but it is important that there must not be any clearance between the edges of the strap and the end faces of the workpiece.

The time between taking the workpieces out of the steamer and the bending process should not be longer than one minute. It has to be kept in mind that as soon as the wood leaves the steamer, it is loosing it's plasticy.

As soon as the workpiece has reached it's shape in the bending process, it has to be fixed. This is usually done by one or two clamps around the edges of the strap. Together with the clamps, the strap avoids spring back and after-bending damages (splits, breaks). The workpiece has to be kept inside the clamp until the wood has cooled down to room temperature and decreased in moisture. Then the strap can be released. To avoid spring backs which might still be possible in that stage, the workpiece can be fixed by small wooden clamps. Bended wood should be fixed until it has reached it's final moisture content to ensure the highest possible accuracy.

Acknowledgements:
Fig. 1, 3 - 6: Eggert, Untersuchung der Einflußgrößen beim Biegen von Vollholz. Diss. Univ. Stuttgart 1995
Fig. 2: Kollmann, Über das Biegen der Hölzer, HZ 78
Fig. 7 - 10: Kollmar, Untersuchungen über das prozeßbed. Versagen von Vollholz-Biegeteilen in der Möbelindustrie. Rosenheim, FH, DA 1993
Fig. 11- 13, 15: GHE bavaria, D - 97 246 Eibelstadt, Deutschland
Fig. 14: Eggert, Materialflußoptimierung beim Holzbiegen. HZ 121

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