THERMO – HYDROMECHANICAL COMPRESSION OF FAST GROWING POPLAR FROM SHORT TERM PLANTATION

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ABSTRACT

Moisture and Temperature do have a considerate impact on wood properties. High temperatures and moisture content soften the wooden structure and allow to compress and to form wood without harming the inner structure. During compression, the structure stores deformation that later can be regained. The elasticity is enhanced proportional to the amount of compression. In wood machining, the material is no longer considered to be a solid body, but a cellular solid. This is will change the prospect on treating wood considerably. Forming perpendicular to the grain will add to milling and sawing and enhance the possibilities of treating timber for constructive purpose. To utilize the deformation, compressing must be done in a different way than when compression is done to enhance the material properties. To establish the densification method, temperature, moisture content and compression speed must be fitted to this purpose. Small, clear samples are compressed varying the parameter mentioned and are being evaluated according to the defined purposes. Measuring the stress strain relationship during the densification process, studying the spring back and analyzing the densification distribution within the cross section enables to evaluate the process parameters.

1. INTRODUCTION

The growing need for energy encourages us to search for new ways of dealing with fossil and renewable energies. There is a call for alternative and renewable energies and the timber industry faces a new competitor on the market for raw material. Although there was plenty of wood available during the last decades and prices were cheap, we face a shortage in wood supply today, and according to that, prices rise again. Wood is one of nature's finest products. It's variability in color, strength and many more lead to a great variety of wooden products. Also, needing only sun, water and time to grow it is cheaply produced and additionally serves as a reservoir for carbon dioxide.

Unfortunately during the last decades the market for building material edged wood into the position of an old fashioned material and concentrated on the development of high-tech materials. Energy still wasn't scarce and high prices were widely accepted. New developments in the wood sector weren't necessary and research concentrated on improving old techniques only. Now scientists working at the Institute of Steel and Timber Structures of the Technische Universität Dresden developed a routine to store and regain elasticity within wood. Compressing wood perpendicular to the grain effects the cellular, honeycomb- like structure to fold itself, when certain values concerning temperature, water content and level of densification are taken into account. The compression is stored in the wood's memory and can be regained to form and bend the material achieving an elasticity of up to100%.

Ordinary wooden products are far from being high- tech. The efficiency of wood is reduced to 50% in the sawing mill: When brought into shape for constructive purpose, 50% of the precious raw material is lost when cutting beams. *Formholz*, produced using the technology of compressing and forming however scores with an efficiency that can be up to 32 time higher compared to beams or even glulam, when log wood is used.

Wood from fast growing plantation serves as energy wood, but although the prices for wood rise, the prices are still too low, to gain an adequate profit. Fast growing trees, in Germany mainly poplar, willow and robinia, are sold on the energy market only, where prices are still low. Higher prices can only be gained if the end product scores higher selling prices or the product itself is scarce.

2. FROM TREE TRUNK TO TUBE

The idea is to inverse the common bending-process by using compressed wood in the first place and to use this to bend the structure in the second step (Fig. 1). After compression, the core is being removed and the halved trunks are glued to form a densified board that can be formed in direction of compression. When done that way, the minimal bending radius is reduced to approximately two times of the thickness of the board, which enables to bend in reasonable dimensions for constructive purpose. Additionally, other than in traditional bending, this process forms perpendicular to the grain

Compressing at 140°C and slow speed enables to store deformation within the wood, which in the second step can be used to bend wood using the stored deformation. Opposite to the most common purpose of compressing wood, that is to improve strength and similar properties, where a regain of deformation is unwanted, the compression must be done in a way to be able to regain it later. Thus the whole process of compressing must be done in a more careful way, to not damage the cellular structure, but only fold it and to be able to regain the deformation reserves stored inside the structure later.

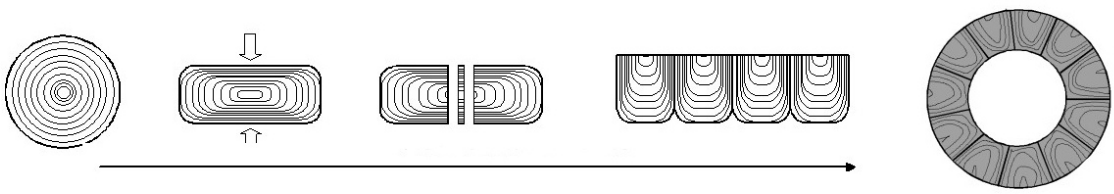

Fig. 1: Fabrication of *Formholz* using log wood.

3. FAST GROWING POPLAR FROM SHORT TERM PLANTATIONS

Poplar is mostly known as low quality wood. Due to its comparatively low strength it is not used for constructive purposes and since its texture is quite bland, it is hardly used within the furniture industry either. The tested wood is taken from a plantation that was set up for research in Methau, Saxony during the 1990s. The distance between the trees was relatively wide, due to a massive thinning after 3 years. So after ten years of growing the trunk diameters varied between 10 and 20 cm. Although the annual rings' width varies between 5 and 10 mm their width is distributed relatively equal. There were rather slim trees with an average annual ring width of 5 and thicker trees with altogether wider annual rings. The clone used was a MAX I. The average density of the samples used was 300kg/m^3.

4. QUESTIONING AND SAMPLES

The samples were cut out of discs with a height of 20 mm. Their size is 40x40x20 mm and they are of clear wood (fig. 2). They were cut out in a way to ensure compression either parallel to the annual rings or perpendicular to them, so the samples are either compressed in radial or tangential direction, considering two different moisture contents. Herein 7% simulate dried wood likely to be available in any sawing mill and 70% fresh, green wood right after the tree was cut down.

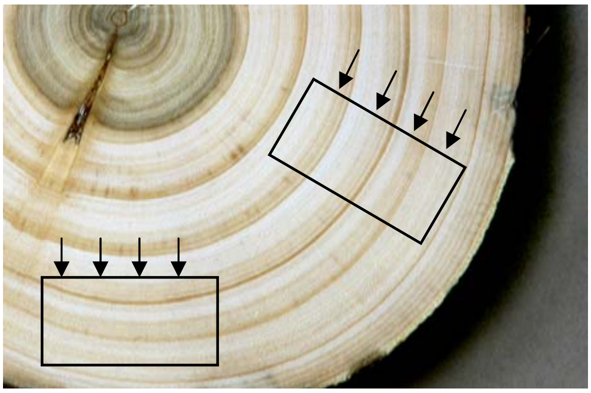

Fig. 2: Samples and their direction of compression

A high moisture content decreases wood's strength, thus softens the structure. This is beneficial to the compression process because the strains will be lower and because, the probability of cellular damages during the structural collapse will be decreased. The samples are preheated and compressed at a temperature of 120°C. Durning preheatment, they are seald to prevent any moisture loss. Also dry samples are compressed at 20°C.

Moisture Content	7%	70%
Temperature	20°C	120°C
Speed of Compression	1 mm/min	4 mm/min
Direction of Compression	tangential	radial

Tab. 1: Samples and their direction of compression

The samples were compressed perpendicular to the grain to 50% of their height. They were compressed at different speed (1 and 4 mm/min) until a densification of 50% was achieved. To study relaxation the samples remained inside the hot press for ten more minutes. The intention is not only to provide a law for compressing different wood species at different temperatures, moisture content and low speed, but also to provide data for the forming process.

5. RESULTS

5.1 Stress- Time Relations

Figure 3 shows a typical stress-time diagramm for densification at a speed of 4 mm/min. The densification progress is stopped, when the preset value is obtained. The sample remains in the press for another ten minutes in which the cellular structure relaxes. Densification and relaxation follow the same track for wet and dry wood, apart from the scale being more than three times higher for the dry material.

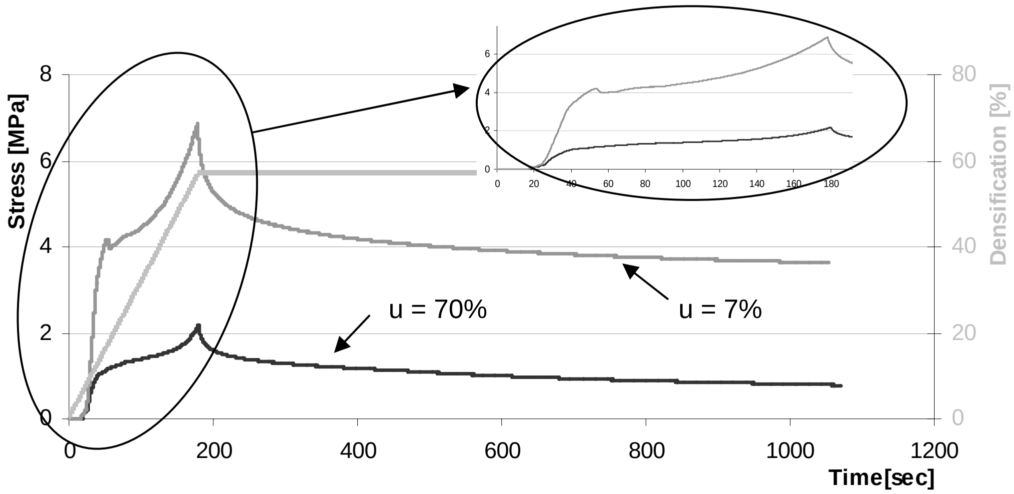

Fig. 3: Stress- Time Relationship for wet and dried poplar during compression and relaxation

During densification three sections are apparent. Within the first section pressure is on the cell walls only, generating elastic deformation. When the pressure rises, cell walls start to buckle and deformation is similar to the the flowing of steel. When the lumen are filled, stress increases again at higher speed and deformation starts to be plastic. To guarantee the “Formholz” process to be successful, plastic deformation should be avoided.

Reaxation is very obviouse in the beginning, but slows down later and seems to approach a defined value. For either amount of moisture this value seems to be 50% of the maximum pressure applied. Futher testing will be necessary.

Moisture softens the structure significantly. The pressure needed to deform to 50% is up to four times higher for dried wood than for green wood (figure 4). Compressing slower guarantees lower stress and less cracking within the structure (figure 5). However there is no clear difference between compressing in radial and tangential direction. Other as spruce, where compressing in the tangential direction is much more difficult, poplar compresses equally good in both direction due to the relatively homogeneouse distribution of pores within the year ring.

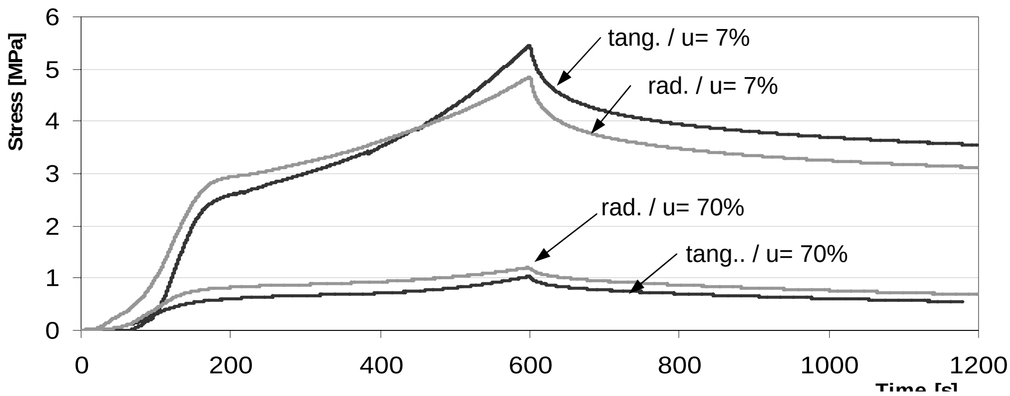

Fig. 4: Stress- Time Relationship for wet and dried wood in tang. and rad. direction

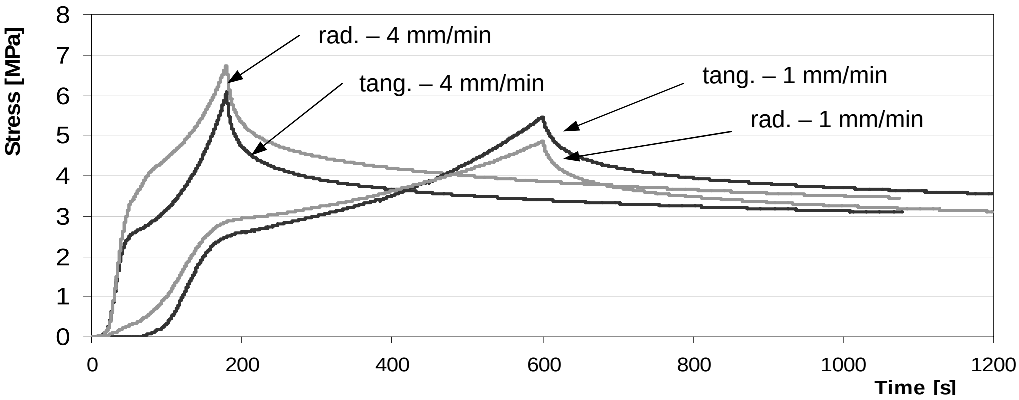

Fig. 5: Stress- Time Relationship at different compression speed in tang. and rad. direction

Compressing green wood additionally reduces the moisture content significantly. Whereas dry wood only loses 30 % of the initial moisture through heating and compressing, green or wet wood is dried down to 50% of the initial moisture content. The absolute numbers are even more obvious: the moisture loss is 3 % for dried and more than 35 % for green wood. This side effect is beneficial for economical reasons, as it reduces drying times and costs connected to it.

5.2 Spring Back

However, compressing green wood seems to be an alternative both for economical and macro-structural reasons, the result for the spring-back shown in figure 6 prove a high moisture content during compression to be inadequate for later use as *Formholz*. Spring-back herein is defined as the percentage of the initial compression that is lost by the elastic reaction when the wooden part (e.g. sample, beam, trunk) is taken out of the hot press.

The spring back is mainly affected by moisture content and post treatment of the sample. Heat, wood type and compression angle however are minor factors. Especially the compression angle can be left unattended when speaking about poplar due to the homogeneous distribution of the lumen within the annual ring and the lack of rays.

Spring back is up to 75% for wet or green wood and 20 to 30% for dry wood. However it still can be reduced, leaving the wood in the press longer and cooling it down to below 40°C. Spring back is increasingly irregular with higher moisture content. Such densified wood can hardly ever be used for neither *Formholz* nor anything else.

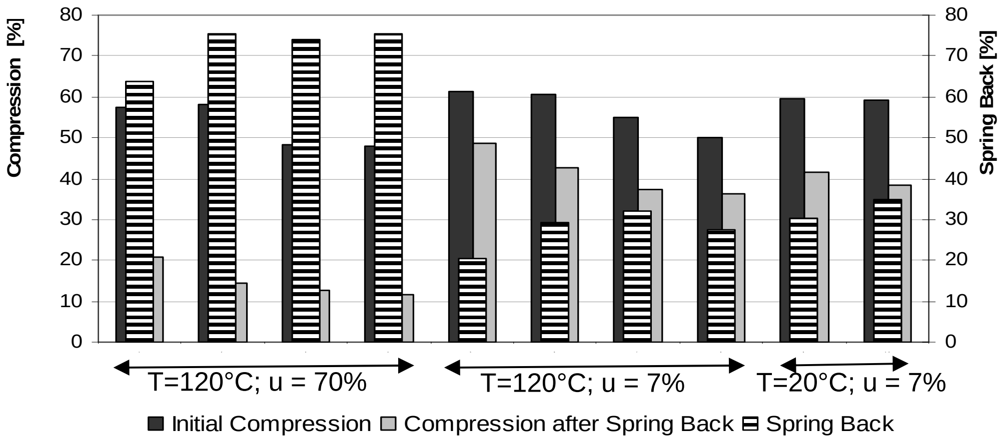

Fig. 6: Spring Back

5.3 Stress- Strain Relations

Comparing on a Stress-Strain base gives further information about the influence of the pre-treatment on the densification process. The aim of the pre-treatment is to reduce the Young's Module to decrease the compressing power and therefore to decrease cracks within the cellular structure. Designing a machine for industrial production of *Formholz*, one also needs to know the values for the forces being applied on the wood and on the machine during the compressing and bending process.

Figure 7 shows the results for compressing in the tangential direction. The pre-treatment of those samples varied considerably. The easiest way of compression is to use green or very wet wood and pre-heat it to 120°C. The flowing starts at a stress of 1 MPa for wet wood and 2,8 MPa for dried, heated wood. The maximum stress to compress to a densification of 50% is 5,1 MPa for dried, heated and 1,8 MPa for wet, heated wood. Unlike steel, wood is not flowing perfectly, but still bearing load. The Young's Module however increases more again when reaching a densification of roughly 45 %. Testing other kinds of timber showed similar results. The quasi flowing ends at a densification of between 50-60% of the pore volume.

Figure 8 shows an overview to stress-strain relationships compressing in radial direction. As mentioned above, there is no noticeable difference of compressing in radial or tangential direction for this type of wood. The speed however is of importance to the maximum strain for compressing a defined value of densification. Loading at a lower speed results in compressing with lower pressure. As relaxation not only takes place after the densification process, but also during it, relaxation is more distinct at lower speed. Reducing the compressing speed from 4 mm/min to 1 mm/min results in a stress diminishment of 0,5 MPa in absolute values. In relative numbers, this is even higher for wet wood, where during the densification not only the cellular structure collapses but also the water is removed form the pores. The more time the water is given to leak out, the less counter pressure it is applying on the system.

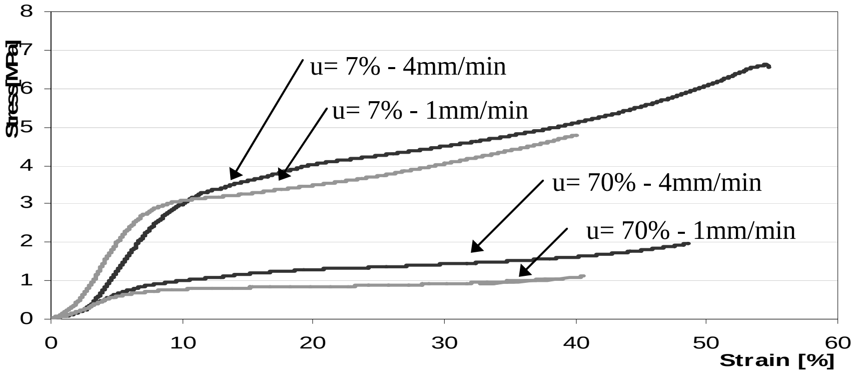

Fig. 7: Compression in radial direction

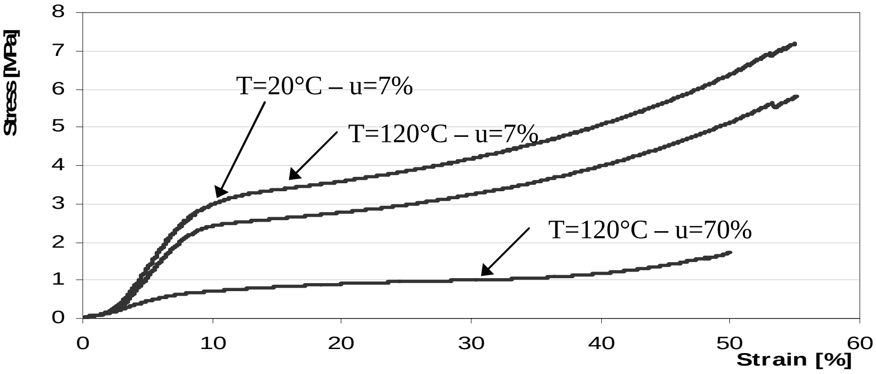

Fig. 8: Compression in tangential direction

5.3 Densification Quality

Figure 9 show CT pictures before and after compression. When compressing for usage as *Formholz*, an equal amount of densification in every layer has to be guaranteed. That even distribution of densification will later guarantee a permanently good bending ability. Accomplishing this is a rather difficult task, especially when compressing softwood in the radial direction. It is hardly not possible to compress the distinct areas of hard latewood and soft earlywood equally and in most of the cases, densification is only stored within the earlywood. The indicator for the densification is the density. Other than compressing wood to enhance the stability and resistance of the material, where a homogenous density is wanted in the end, layers of high density in the original sample must be recognized as layers of high density in the compressed condition.

Poplar shows good compression results in both the radial and the tangential direction. The samples were compressed to 50 % of their height, accomplishing a densification of 50 %. Areas with high density remain areas with high density relatively to the average density. The same is valid for areas with low density. The annual rings are clearly notable, in particular in the tangential compressed samples. But also the radial compressed samples show improved regularity in the amount of densification compared to softwood. When compressing into the radial direction shear forces cause the annual rings to slide. To prevent that, several beams can be laid next to one another and dummy beams are to be placed on the borders while compressing. If not done that way, the annual rings slide, as it is notable in Figure 9. This not only is unfavorable to the internal structure, but also causes high densified areas, wherein recovery is most likely not possible.

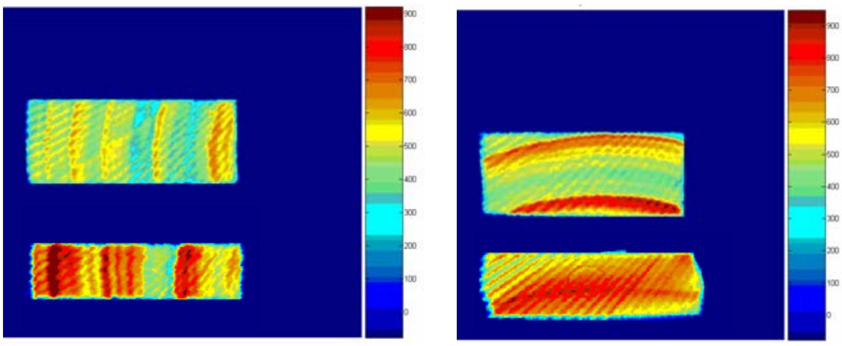

Fig. 9: Density distribution in noncompressed and compressed poplar for tangential direction (left) and radial direction right. *CT by J. Schreiber*

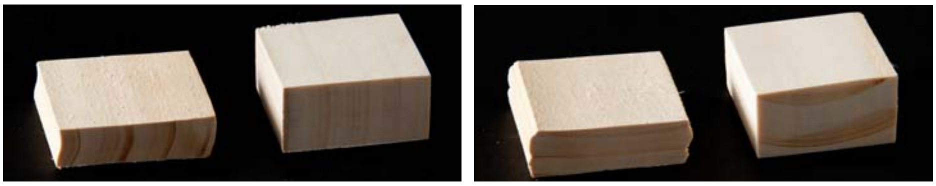

Fig. 10: Compressed and uncompressed sample. Right: tangential direction; left: radial dierction.

6. Conclusions

Testing so far proves fast growing poplar from short-term plantations to be well suitable for usage as *Formholz*. The low density, highly porous structure allows to compress at low pressures and results in an even distribution of densification. Other than with spruce, compressing in the tangential direction leads to no major problems. Compressing in tangential direction is even easier for poplar, because the distribution of densification is more even. Green wood can be compressed easily, but because of the considerable spring back it is not recommended to do so, unless a longer drying phase in the hot press is allowed. Futher test on regaining the deformation reserves and actual forming are still to be done.

Fig. 11 : Uniaxial compressed logwood

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