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# Textile reinforced wood construction

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ABSTRACT: Generally spoken, difficulties in wood construction arise from four sources: the poor material efficiency compared to technical materials, the low strength spectrum, anisotropy as well as preservation. This paper deals with several technologies coping with these drawbacks. A new technology that transforms raw wood into profiles which considers the material as a cellular solid is being presented. Technical textiles turn out as a versatile technique that improves structural performance and serviceability.

## 1 INTRODUCTION

The importance of wood as a structural material and its contribution for a sustainable development beyond the building sector will decisively depend on the scale to which our tasks can be solved in keeping with technical and economical conditions. Therefore it is not enough to dispose of a renewable raw material it also has to come up to today's and future expectations.

Engineers decide on the use of materials according to rational points of view. In the course of their academic education they deal with a great variety of building and engineering materials that still will increase in the future. In contrast to craftsmen engineers are not bound to use a special material, nevertheless wood is excluded in many fields of engineering right from the beginning. Only in civil engineering and architecture its application is still seriously taken into account. Despite ecological advantages a decision in favour of wood always requires technical and economical arguments. For that reason science and technology should create the preconditions for an efficient and more frequent use of this resource.

The forest is not only one of the greatest but also one of the cheapest producers of material in the world. It is difficult to believe that a material produced on one third of the area of my country with the help of solar energy is undercut by those being produced using large amounts of fossil energy and capital. One significant reason for this can be seen in the fact that the forest is not considered as producer of material but as producer of cross sections. We will have a closer look at this later.

Moreover, we have to ask what further disadvantages prevent the use of wood for technical applications and whether they can be removed or not. In particular these are:

1. the low strength spectrum as compared to structural materials
2. the directional dependence of the mechanical properties, the so-called anisotropy, and
3. the low weather resistance of domestic softwoods.

## 2 DENSE, DENSER, DENSEST

Wood has a well-balanced profile of properties without reaching outstanding values except its environmental friendliness as long as this is not ruined by additional treatment. Also the price per unit mass, that even allows a thermal use, is cheaper than of most other materials of our time.

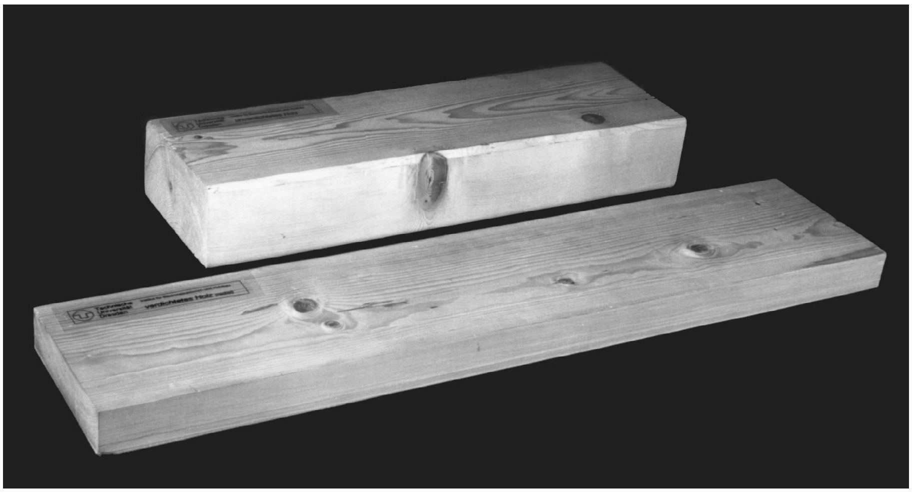

Figure 1. Spruce squared timber cross section before and after densification.

The mechanical parameters play a central role in load bearing structures and mainly depend on density and growth structure. The differences among species amount to approximately a power of ten. The comparison between structural timber and clear wood presents additional differences so that the strength potential increases to largely one order of magnitude.

The densification of wood (see fig. 1), especially hard wood, using heat and pressure is known in wood technology since long. Also nowadays resin-bonded veneer panels, e.g. for electric installations, are produced in this way. The precondition for the densification is the cell construction of the wood that allows densification by means of a press after the softening temperature of the lignin was reached. Thanks to this thermo-mechanical treatment strength and stiffness can be increased proportionally to densification. Further heating above 200 °C leads to an increase in biological resistance, so that the heat influences two important properties, i.e. strength and durability (see fig. 2).

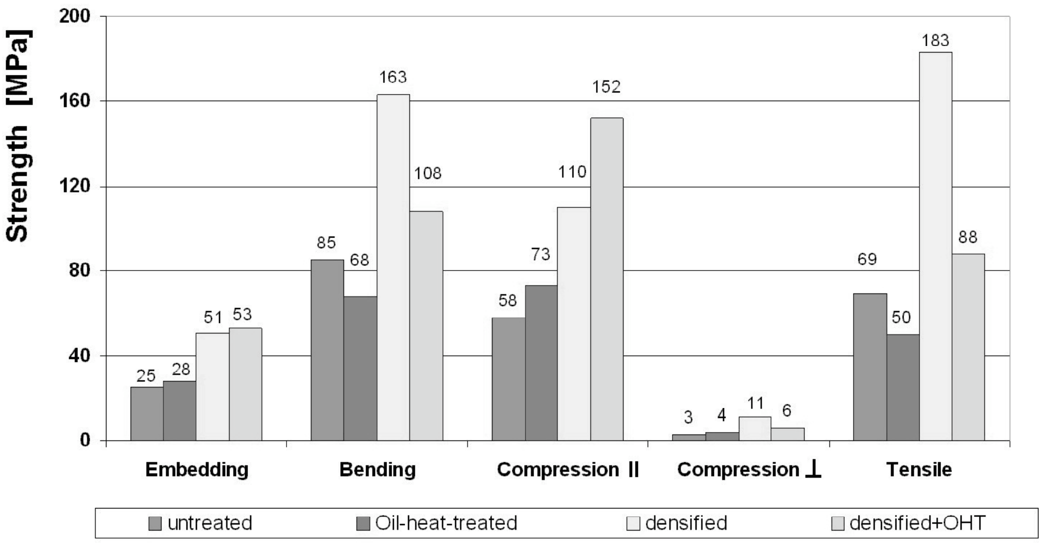


Figure 2. Strength values of soft wood (spruce) with parallel fibres, untreated; oil-heat treated; densified; densified and oil-heat treated.

## 3 FROM A TRUNK TO A CROSS SECTION

The growth of a tree and its cutting in the saw mill on the one hand lead to a lot of waste and on the other hand to full cross sections that as compared to technical profiles reach low area moments. The forest as producer of material belongs to the most low-priced sellers, but its competitiveness gets lost while the raw material is transformed into cross sections. Therefore it is absolutely necessary to check all possibilities of material economy in the production of cross sections.

The techniques in the saw mill present the first and most important step in the production of cross sections. The relation between output and waste significantly determines the processing and thus the price margin of other partly competing wooden products. This technique considers only one dimension and favours "one-dimensional" kinds of trees. So that in case of reforestation coniferous soft wood, especially spruce, is preferred to hard wood typical for the region as e. g. oak-trees or beeches with their widespread tree-tops.

Wood is said to be worked easily, but the opposite is true. Wood is transformed into cross sections by cutting and joining with synthetic bonding agents afterwards. This does not demand any knowledge of the microstructure. But just this presents a great potential for the development of new techniques and products that has not been paid sufficient attention to in science and technology until now.

The saw mill delivers a squared rectangular cross section that - as compared to technical profiles made of metal or plastic - has a low efficiency of material. If one adds the bad output of wood by sawing one receives a quite dramatic result. Starting from round or sawn timber figures 3 and 4 demonstrate the manufacturing process and a circular hollow cross section respectively.

At first sight we are tempted to assume especially good qualities for bearing structures there where we find high strength. But this has to be looked at more closely. What do engineers do when they are planning bearing structures? They transfer forces and moments with the help of the product of a material factor, i.e. the strength, and a geometrical factor, i.e. the cross-sectional area or the moment of area. In simple words: if a material is only half as strong its cross-sectional area will be doubled. But it cannot be more than doubled because with area moments the distance between cross section and neutral fibre is raised to a power. Therefore structural components are easier to be dimensioned by varying the dimensions of the cross section but by changing the strength class.

The way of choosing round or square solid cross sections in timber engineering hides the fact that the resource productivity is low. In this respect a comparison between squared timber and technical profiles shows a relation of approximately 1:15, what on the one hand results from the losses in the saw mill and on the other hand from the low moment of area of the solid cross section.

Since timber does not directly depend on the cross section it has to be optimally placed there according to mechanical considerations and has to fulfill the following three conditions:

1. the cross section must not be limited by transverse or longitudinal dimensions of the tree
2. it has to be efficient, i.e. it has to have a great area moment for a given area
3. a cheap production of large quantities must be guaranteed

Squared timber does not meet condition 1 and 2; glued timber does not meet condition 2 and 3. Only the shaped timber profile shown in figures 3 and 4, based on a new understanding of the material, has the potential to meet all tree conditions.

## 4 TIMBER IN TOP FORM

As far as production techniques are concerned timber construction relies on two basic processes: dividing, i.e. sawing, planing, shredding etc., and then joining by synthetic or metallic fasteners. Already nowadays there is a great variety of possible constructions based on each of these basic processes and their combinations. Imagine this variety could still enlarged by one or two additional ones.

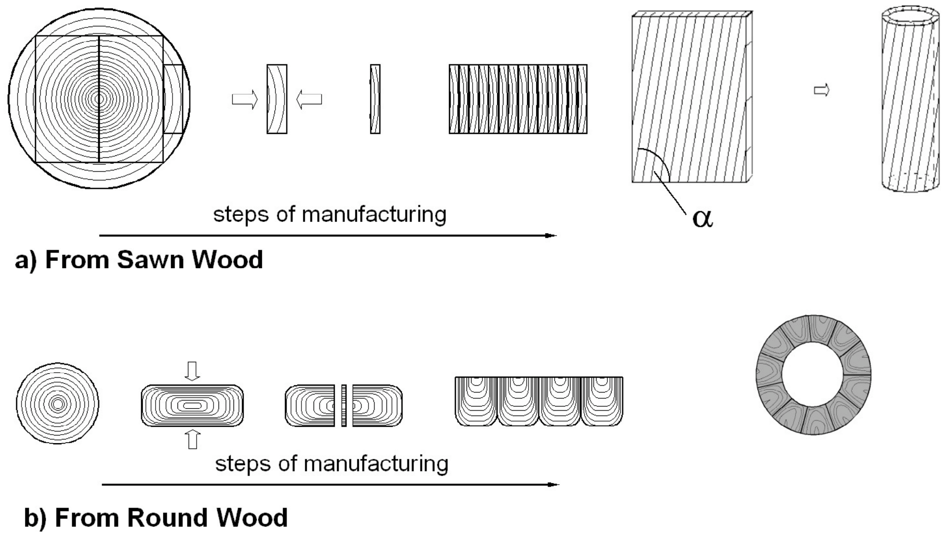


Figure 3. Process of production of shaped wooden profiles made of square or round timber.

Figure 4. Ring-shaped cross section made of densified half-round timber

Domestic soft wood has a porosity of about 60 %. Its polymeric structure allows slight plastic deformation transversally to grain at a temperature of 140 °C and a pressure of 5 MPa. Thus the dimension of the cross section can be approximately halved (see fig. 1), whereby the micro-structure of the wood folds up. This possibility to improve mechanical properties was already mentioned in the preceding paragraph.

It is also important to know that it is possible to nearly completely reverse and fix the compression without causing any damage to the microstructure if a suitable process is applied.

Its great porosity allows to consider the wood in a completely new manner as a foam-like, cellular material that now indeed becomes a material easily to be processed. Thus fracture elongation transversally to grain increases from one to 100 per cent, i.e. by two orders of magnitude. Soft and hard wood are both suited for this.

Starting from these thoughts at the Institute for Steel and Timber Structures there were made glued laminated timber boards and densified in the direction of the plane. Afterwards under certain heat and humidity conditions there were produced prismatic cross sections reversing the compression by completely folding up the cells.

The bending radius of the deformation depends on the preliminary densification. Depending on the production technique the minimum bend corresponds to about twice the thickness of the board. This way basically all open and closed prismatic cross sections of any length can be produced.

According to this method, which meanwhile was patented, tubes of structural dimensions have been successfully produced. Figure 3 shows an example that begins with the densification of round timber. The division in the direction of maximum density and subsequent gluing lead to a solid panel that can be transformed into a tube by means of thermo-mechanical treatment. As compared with the round timber material economy amounts to about 80 per cent. 50 per cent of it can be saved by avoidance of waste in the saw mill and the rest by an efficient placement in the profile.

## 5 THREAD MEETS FIBRE

When timber is used for bearing structures not only mechanical and biotical behaviour are of great importance but also its anisotropy. The first-mentioned can be improved by sorting and thermal and/or thermo-mechanical procedures whereas the directionality of strength is met by different measures in design.

Strength and rigidity can very efficiently be compensated in the course of dimensioning the cross section in longitudinal direction. But even experienced structural engineers face problems dealing with shear and transverse stresses. Meanwhile a lot of different solutions and design methods are available that led to complex special knowledge. Therefore it is desired that the problems connected with anisotropy shall be met by a universal technology.

A look at nature could teach a lot of things because many natural constructions meet mechanical stresses by optimally directed fibres: as e.g. crotches of a tree, blades of straw or muscles. Fibre reinforced plastics present a technical application according to this example. The connection of threads to flat or three-dimensional structures is a subject of textile technology. The Collaborative Research Centre (SFB, Sonderforschungsbereich) 528 “Textile Reinforcement for Structural Strengthening and Retrofitting” at the Faculty of Civil Engineering examines their application in civil engineering.

This Collaborative Research Centre also elaborates the fundamentals of textile reinforcement of timber structures. The cooperation with the Institute of Textile and Clothing Technology enables the timber engineers in Dresden to apply fully fashioned stress related textile reinforcements made of glass, carbon, aramide or natural fibres that are glued on by synthetic resins afterwards.

Figure 5. Cross sections of tubes with textile reinforcement

Technical textiles help to build a bridge between timber engineering and light weight construction what is thought to lead to a completely new quality in the use of this renewable resource.

Besides the mechanical behaviour of the construction the low durability of organic building materials proves to be a decisive disadvantage for exterior application that nowadays is answered by modified wood properties and structural design. But in both cases will arise additional costs.

The complete reinforcement of whole building components in connection with surface treatment as in light weight construction will not only provide structural reinforcement but also an effective protection against weathering. This is an important advantage not only what concerns humidity but also with regard to a corrosive environment.

## 6 CONCLUSION

The presented developments deal with all shortcomings of present technical applications of wood and in the author's opinion fundamental solutions are offered. This concerns the efficient use of the raw material that leads to low material prices; the densification of wood that surmounts the limits of the strength classes; textile reinforcement as technology that completely solves the problem of anisotropy at a favourable price and also provides weather protection; and the shaping of efficient cross section profiles as probably the most far-reaching innovation.

These new developments can be applied everywhere where cross sections are needed. These may be bearing elements in civil engineering as columns and girders, in light-weight and equipment construction, but also non-bearing parts for furniture or interior work. Moreover a lot of things with an open or closed prismatic cross section can be produced this way, e.g. cable drums, poles, barrels, tanks, rotor blades or hulls.

Wood will become of greater technical importance if its properties, cross sections and production techniques can come up to the expectations of engineers more properly. Old constructions always are bound to meet old reservations. So it is easier to apply new methods as astonishingly as this may sound. Wood has the potential for innovations based on material and techniques. That there are few innovations is not to be explained by the wood itself but by structures impeding its development.

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