THE CONCEPT OF VALUE ACTIVATION
- A BETTER UTILIZATION OF WOOD

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ABSTRACT

A new manufacturing system has been proposed in order to improve the utilization of wood. This concept, called Value Activation, is focused on the basic understanding of wood, and the fact that there are properties that are not fully exploited in conventional wood manufacturing systems to date. The strategy is to activate these inherent properties by a better understanding of the fundamental behaviour of wood, combined with new applied process technology and the development of the required manufacturing systems.

One basic idea within this concept is a new sawing pattern called star-sawing, which produces timber with two different shapes, viz., timber with rectangular and triangular cross sections. This method facilitates an efficient production of radially sawn timber with vertical annual rings, and without pith and juvenile wood. Computer simulations and in-practice tests demonstrate a high volume yield for star-sawn timber of pine and spruce. Results also show that shape distortion and crack formation as a result of any moisture change in this timber are minimized. Indentation resistance is higher and in-plane movement lower in radial than in tangential sections.

The overall properties and appearance of radially sawn timber are seriously affected by splay knots and the associated fibre disturbance. These defects are often not acceptable in further processing. Accordingly, tests have been performed to remove such defects in star-sawn timber in order to produce knot-free boards and solid wood panels. In this process, the timber is finger-jointed to form knot-free lengths suitable for e.g. ceilings and floors. In addition, such lengths of the triangular timber may be used as raw material to produce high quality solid wood panels (solid laminated wood products) with vertical annual rings.

Key words: wood processing
star-sawing
volume yield
glulam laminates
solid wood panels
INTRODUCTION

In earlier days, in order to obtain a wood product with the most desirable behaviour, the skilled craftsman knew, by tradition and experience, how to choose the particular parts from a selected individual tree stem. In other words, the specific character and properties of wood were used in an extraordinarily efficient way. As a result of this careful selection process combined with certain special construction techniques, the performance and condition of many old wooden constructions are still sufficient. Today’s manufacturing systems do not utilize such an individual selection of desirable properties. In the future, however, it may be possible to measure detailed properties of the individual stem and, based on these data and on the specifications of each component, it may be conceivable to produce components with a substantial high value. This demands a better knowledge of the fundamental behaviour of wood combined with a considerable development in advanced and efficient manufacturing systems.

In order to develop a manufacturing system for the better utilization of wood and its inherent properties, a long-range integrated Research and Development program, called Value Activation, has been carried out in recent years at the Royal Institute of Technology, Division of Wood Technology and Processing. This concept, (Wiklund 1991, 1993) is focused on achieving a basic understanding of wood and of those properties that are not fully exploited in conventional wood manufacturing systems to date. The strategy is to activate these inherent properties and thus add economic value to completed wood products. In order to achieve this, a better knowledge of the fundamental behaviour of wood is needed together with new applied process technology and the development of the required manufacturing systems.

One idea that has been invented within the Value Activation concept is a radically new method of sawing logs, based on a new sawing pattern. This new method, called starsawing, facilitates the efficient production of timber with vertical annual rings, and in addition, timber in which pith and most of the juvenile wood has been excluded (Sandberg 1996b). It has been demonstrated that this timber has a better dimension stability and shows less tendency to crack formation when kiln dried and subjected to moisture cycles, due mainly to the favourable orientation of the annual rings and to the exclusion of the juvenile wood (Sandberg 1996a, 1997a).

An integrated idea within the concept is also the design of manufacturing systems for calculating and producing a mix of components which can give superior performance and higher value than each individual element. The components will be specified by requirements concerning for instance, hardness, form stability, appearance and strength durability. Subsequently, these components will be parts of combined solid wood products, held together by adhesives, where each part contributes with its specific properties to the optimal function of the entire system. Some important properties are: natural durability, annual ring orientation,
density, coatability and aesthetics. Examples of such products are solid wood panels and window constructions. These kinds of wood products have, presumably, a high potential considering the strategies of future sustainable development.

The purpose of this paper is to present some important aspects within this concept of Value Activation. Mainly, we focus on the star-sawing technique and characteristic features of star-sawn timber. In addition, we also describe some basic principles for gluing triangular profiles in order to produce solid wood panels with vertical annual rings.

RADially SAwn TIMBER

It seems obvious that, if timber is sawn radially from the log without pith and juvenile wood, properties will be obtained which are much better than those of conventionally sawn timber. Star-sawing is a method for producing such timber. This saw pattern, shown in Figure 1, is a conversion technique which produces timber with two different shapes, i.e. with rectangular and triangular cross-sections. It is also clear that this timber has flat sides approximately parallel to the primary anatomical directions in wood, i.e. either radial or tangential sections.

![Schematic illustration of a new sawing pattern called star-sawing.](image)

There are several other methods of producing timber with vertical annual rings. The methods which give timber with a rectangular cross-section adopt in most cases the traditional quarter sawing pattern, as in Figure 2a. Other methods which give timber with vertical annual rings involve the sawing of sectors with a more or less triangular shape, as in Figure 2b. A compilation of some of these methods has been made by Polaczek (1990).
FEATURES OF STAR-SAWN TIMBER

Dimensional stability

Wood is an *anisotropic* material, i.e. a material with directional properties without symmetry. However, wood is also generally considered to be an *orthotropic* material with distinctly different properties along three mutually perpendicular directions, the longitudinal, radial and tangential directions. Many influential properties of wood, such as shrinkage and elasticity, are distinctly different in these different directions. The well-defined difference in properties between the tangential and radial directions is referred to as transverse anisotropy.

The transverse shrinkage and swelling anisotropy of the wood means that timber exposed to moisture changes usually suffers a change both in its dimensions and in its shape, i.e. deviations occur from the original, usually right-angled parallelepipedal, shape. The changes in shape may appear as distortions and angular changes in the cross-section and are due mainly to the fact that the sides of the timber are not parallel to the radial and tangential directions.

Figure 2. Example of two cutting patterns which give timber with vertical annual rings: quarter sawing (a) and sector sawing (b).
Figures 3a and 3b show the transverse deformations after drying of conventionally sawn and star-sawn timber respectively. As can be seen, the distortion of the conventionally sawn timber is much greater than that of the star-sawn timber with its vertical annual rings. It is well known that radially sawn timber with vertical annual rings shows no cupping and that it warps less than conventionally sawn timber. It also shrinks and swells less in width (Kollmann and Côté 1968). The dimensional changes associated with moisture changes are, of course, still present but the radial moisture movement occurs only along the width of the timber and the tangential changes only in its thickness direction. The sides of the timber are thus parallel to the transversal directions of the wood and the movement as a result of any moisture change can be predicted.

In-service movements of solid wooden floorings of Scots pine have been measured over a period of one year (Wålinder 1996). This investigation showed lower in-plane movements in floorings with radial sections than in floorings with tangential sections. The ratio of tangential to radial movement was of the order of three, which is greater than the expected tangential to radial shrinkage ratio of about two.

Based on the condition that the moisture movement over the width of a board should not exceed the true radial moisture movement by more than ten per cent, Sandberg (1995) suggested that timber of Scots pine and Norway spruce may be considered to have vertical annual rings if the angle between the flat side and the tangent to the annual ring at half the thickness ranges between 60 and 90 degrees.
Juvenile wood

It is well known that the juvenile wood, the annual rings closest to the pith, differs considerably from the wood located in the periphery of the trunk. In the case of Norway spruce, it has been found, for instance, that the fibril angle is greater in the juvenile wood than in the mature wood, which means that timber which contains juvenile wood is deformed during drying (Danborg 1990). Sandberg (1997a) has shown that, for Scots pine and Norway spruce, there is a clear relation between the occurrence of cracks in boards from butt logs and the distance from the pith from which these boards have been sawn. Boards containing pith, and boards without pith where the shortest distance between the pith and the piece of wood is less than 30 mm, have considerably more cracks than boards sawn at a greater distance from the pith. These disadvantages associated with pith and juvenile wood mean that, to obtain straight timber free from cracks, these parts of the log should be removed from the rest of the wood already at the time of sawing.

Knots

In star-sawing, as in all radial sawing methods, the sawing kerf splits the knots in the length direction. This timber therefore has a greater proportion of so-called splay knots than flat-grained timber produced by through-and-through sawing and square-sawing. These knots are often unacceptable both aesthetically and from a strength viewpoint, and they must be removed. Depending on what final product is to be produced, the extent of defects, e.g. knots, pitch pockets and reaction wood allowed in the product will vary.

Figure 4 illustrates fibre disturbances around knots. These disturbances reduce the strength and can cause pick-up during finger-jointing and planing. In the production of e.g. high-quality furniture, fibre disturbances can be troublesome because they give locally different moisture movements and can lead to undesirable visual changes in the surface. For certain applications, it can therefore be advantageous to remove the surrounding fibre disturbances together with the knot.

Figure 4. Fiber disturbance around knot in Scots pine.
A large proportion of the knots found in a star-sawn triangular profiles, primarily from butt logs, have proved to be less suitable for the further refinement of the wood and they must be removed (Sandberg et al 1996). A great advantage when knots are to be removed from the triangular profiles, as well as from star-sawn rectangular boards, is that the knots in these boards are always visible on at least one of the surfaces, which is not the case with conventionally sawn timber. This means that when the knots in a triangular profile have been removed, there are no remaining hidden knots which may appear in subsequent operations.

Hardness of radial and tangential sections

Hardness, i.e. the indentation characteristic, is a particularly important property of wood affecting the in-service behaviour and durability of wooden products used as wearing surfaces, for example wooden floorings and various furniture applications. A comparative Brinell hardness test of tangential and radial sections was reported by Holmberg and Wålinder (1997). In this method a steel ball 10 mm in diameter is pressed under a normal load of 490.5 N into the surface of a flat specimen. Table 1 summarizes the measured Brinell-hardness (H_b) and material data from this investigation. The radial sections show a slightly higher H_b-value than the tangential sections.

Table 1. Measured Brinell-hardness (H_b) with standard deviation (std) of radial and tangential sections of pine at a moisture content u = 12%. Density measured at u = 6%. Each value is the mean of 77 specimens (Holmberg et al 1997).

<table>
<thead>
<tr>
<th></th>
<th>Hardness, [H_b] (std)</th>
<th>Density [kg/m^3]</th>
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</thead>
<tbody>
<tr>
<td>Radial section</td>
<td>2.0 (0.2)</td>
<td>505 (50)</td>
</tr>
<tr>
<td>Tangential section</td>
<td>1.8 (0.3)</td>
<td></td>
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</table>
The star-sawing pattern is well adapted to the circular cross-section of the log. The sawing pattern in its basic design gives six pieces with a triangular cross-section and six pieces with a rectangular cross-section. However, depending on the desired timber thickness and the dimensions of the triangular profiles, several more rectangular pieces can be sawn to maintain a high volume yield. In the case of non-circular logs, it is also possible to adapt the sawing pattern to the shape of the log. Non-circular logs usually contain reaction wood in parts of the cross-section. In star-sawing, the log can be positioned during insertion so that the reaction wood reject is minimized. It is also possible to saw timber pieces with a large proportion of reaction wood for use in products where the properties of the reaction wood are particularly valuable.

Removing the pith and the juvenile wood is one of the most critical steps in star-sawing. The path of the pith in the length direction of the stem is often very irregular. Top fractures and other types of damage which frequently arise during the growth of the tree often cause a fairly large displacement of the location of the pith. If the log is crooked, the pith follows this crookedness, at the same time as the pith becomes displaced from the geometrical centre of the log cross-section. This means that high demands must be made on the insertion of the log so that the pith and the surrounding juvenile wood can be "captured" and separated from the other wood.

The appearance of the star-sawing pattern means that the width of the timber is considerably smaller than in e.g. square sawing, for the same log diameter. This means that star-sawing is best suited for large logs where the top diameter is greater than 200 millimetres (Sandberg 1996b). The dimensions of the timber with a rectangular cross-section have been chosen so that they agree with the standardized dimensions used in e.g. Sweden (SIS 1970). In the case of triangular profiles, there are no standardized dimensions and, in the sawing carried out, triangular profiles with sides of 60 to 140 millimetres have been obtained. Besides the timber from the actual star-sawing, side boards are also obtained from the slabs. These boards have horizontal annual rings but with a uniform annual ring direction and they are often knot-free and of very high quality. In order to develop a system for the star-sawing technology and to test the properties of the sawn timber and of the products in which the timber is used, a pilot plant for star-sawing has been built. The sawing is carried out mainly in a horizontal bandsaw which has been rebuilt to cope with star-sawing.

The timber sawn in the pilot plant has been dried in a chamber drier at a sawmill. The kiln schedules used are the same as those used to dry conventional timber at the sawmill. In the drying, the triangular profiles have been stacked in groups of three. In the stacking of the triangular profiles, the tangential surface, from which evaporation is considerably more rapid than from the radial surface, is always placed against some other surface to ensure some degree of deceleration of the moisture evaporation.
Volume yield in star-sawing

The basic idea of star-sawing is to obtain a product with the highest possible value from a given raw material. This means that the volume yield in the sawing need not necessarily be maximized. The volume yield is, however, very important when both from an economic and an environmental viewpoint. For this reason, star-sawing has been simulated with the so-called OPTSAW-system, a computer-based simulation aid, which enables quantitative and economic relationships between the quality of the log and the quality of sawn timber to be analysed (Drake et al 1987 and Liljeblad et al 1988). In order to simulate star-sawing, new software has been developed (Sandberg et al 1993). In addition, about 1000 cubic metres of timber have been sawn in the star-sawing pilot plant. Continuously during the test sawing, logs have been chosen to determine quality and volume yield. On the basis of the results obtained, the insertion and sawing methods have been refined.

The simulations of star-sawing as well as the test sawing show that the yield in star-sawing is considerably higher than in traditional patterns of cutting, e.g. through-and-through sawing, square sawing and quarter sawing. Figure 5 shows the volume yield versus top diameter of the log from trial sawing and simulations of the star-sawing method (Sandberg 1996b). The log volume is here calculated as the top cylinder volume, and the yield with respect to the top cylinder volume varies between 0.50 and 0.75. Approximately 50 per cent of the sawn volume is timber with a rectangular cross-section. Boards obtained from slabs have not been included in this investigation. The total yield is not noticeably affected by whether or not the yield of timber with rectangular cross-section is maximized. The volume yield of logs with a top diameter greater than 28 centimetres is about 0.70 for the total yield and 0.40 for the rectangular timber.

The yield decreases strongly for small log diameters, especially when the log diameter is less than 200 millimetres. There are several reasons for this, the most important being that the standardized dimensions for rectangular timber agree poorly with the sawn dimensions. This causes large wastage in the edging stage. From a handling and allocation viewpoint, small timber dimensions are usually not preferable to coarse dimensions. The knots in radially sawn timber can also have such an extension in the timber, especially in small dimensions, that they constitute a great risk of failure already in an unloaded state.
Figure 5. Volume yield (top cylinder volume) in star-sawing for different top cylinder diameters (Sandberg 1996b).

PRINCIPLES FOR GLUING TRIANGULAR PROFILES FOR SOLID WOOD PANELS

In general, board materials manufactured by gluing together pieces of wood side by side are called solid wood panels. A solid wood panel is usually manufactured from planks which are cleaved longitudinally into lamellae and are planed before being glued together into a board. This method of manufacture gives large volume losses and lamellae are glued together with different annual ring orientations. Star-sawn triangular profiles, on the other hand, can be used as raw material to produce knot-free solid wood panels with vertical annual rings. The further refining of the triangular profiles takes place in five main steps:

1. Removal of unacceptable knots and other defects.
2. Finger-jointing of knot-free lengths
3. Planing of triangular profiles.
4. Gluing of triangular profiles into blocks.
5. Further treatment of blocks through planing and polishing, or splitting of the blocks into boards or other components with vertical annual rings.

Finger-jointing of triangular profiles is in principle carried out by the same method as is used in the finger-jointing of conventional wood. Certain modifications of the equipment are necessary to adapt e.g. transport and holding devices to the triangular shape of the wood. Different finger lengths are used in the join depending on whether the joined wood is to be used for construction purposes or in applications where the strength of the join does not have high priority. The wood can be either joined continuously and then cut into desired lengths or joined directly into certain length modules. In each join, one of the pieces shall be displaced half the division of the fingers to avoid displacement in the join which in subsequent treatment operations can cause volume losses.

In the finger-jointing, one should try as far as possible to keep together the wood sections cut from the same triangular profile to obtain a homogeneous annual ring structure.
(alignment fitting) across the finger-joint. In order also to minimize stresses which arise in the join because of different swelling and shrinking movements in the different directions of the wood, the annual ring orientation shall coincide in the joined pieces (Sandberg 1997b). Figure 6 shows examples of a finger-joint where the annual ring orientation in the joined pieces has been disregarded, and also a join where two pieces from the same wood section have been joined after an intervening knot has been removed.

![Figure 6. Examples of a finger-joint where the annual ring orientation in the joined pieces has been disregarded (to the left), and a joint where two pieces from the same wood section have been joined after an intervening knot has been removed (to the right).]

The finger-joint can be oriented in two different directions in relation to the annual ring orientation in the cross-section of the triangular profile, i.e. parallel to the tangential surface of the triangular profile or parallel to one of its radial surfaces. In general, it is favourable to have radial surfaces than tangential surfaces when pattern fitting is desired between the joined pieces. In tests, it has been found advantageous to orient the finger-joint parallel with the surface which in subsequent treatment steps is to be glued into the construction. This is, on the one hand, because errors develop in the surface in the transition between the joined wood pieces and, on the other hand, because the join can become wave-shaped in the surface because a lack of full parallelism between the direction of the fingers and the surface leads to an uneven pressure during pressing.

Figure 7 shows the surface of a glued block of triangular profiles with visible finger-joints. The orientation of the finger-joint parallel to the surface in the triangular profile which will later be glued into the block means that the characteristic zigzag pattern of finger-joints becomes visible on the surfaces of the block.

The joined triangular profiles are planed on all sides. In order to facilitate the subsequent pressing of the profiles into blocks and to determine the height of the glued block, one of the edges of the profile is planed off. The triangular profile is oriented before the planing so that the surface obtained when the edge is removed can be used to achieve the correct annual ring
orientation in the glued block. After the planing, glue is applied to two of the four surfaces of the triangular profile and the profiles are placed together into a block with the same annual ring orientation, see Figure 7.

A pilot plant has been built to remove defects from triangular profiles and for the joining, planing and gluing of these profiles into blocks. The aim is to create on a small scale new production technology for the gluing of triangular profiles. Properties of different products manufactured by the proposed method will also be tested.

![Figure 7. Surface of a glued block of triangular profiles with visible finger-joints (coloured glue).](image)

The volume yield has been studied in the manufacture of two grades of material, one with a finger-joint and one without a joint. Table 2 shows the yield for each part operation, i.e. the analysis of each operation is based on 100 per cent input material to that operation. In the investigation, the length of the joined boards has varied depending on the number of joints. A large number of joints gives a shorter length than when the number of joints is few. The losses in the final adjustment of the block length have therefore been greater than can be expected in an industrially adapted plant. The yields of the final production stages, splitting and polishing are based on the following assumptions: if the block has a height which is greater than 60 mm, three boards are produced from this block, otherwise only two boards are produced. Each saw cut is assumed to remove 3 mm and the polishing loss is assumed to be 1 mm per board surface, i.e. 2 mm/board. The losses in format cutting of the boards and in edge polishing have not been included in the yield calculations. As shown in Table 2, the most demanding steps are the removal of defects, planing, splitting and polishing of the blocks into finished boards. Altogether, these production steps cover more than 93 per cent of the total loss in the solid wood panel manufacture.
Table 2. The yield for each part operation. The analysis of each operation is based on 100 per cent input material to that operation.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Yield (%)</th>
<th>Proportion of total loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td>87,2</td>
<td>27,7</td>
</tr>
<tr>
<td>Finger jointing</td>
<td>98,3</td>
<td>3,0</td>
</tr>
<tr>
<td>Planing</td>
<td>76,6</td>
<td>43,5</td>
</tr>
<tr>
<td>Gluing of blocks</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>End cutting in blocks¹)</td>
<td>97,4</td>
<td>3,7</td>
</tr>
<tr>
<td>Splitting, polishing²)</td>
<td>84,2</td>
<td>22,1</td>
</tr>
<tr>
<td>Total of all operations</td>
<td>53,8</td>
<td>100</td>
</tr>
</tbody>
</table>

1) The variation in the length of the triangular profiles included in the blocks has been much greater than can be expected in an industrial plant.

2) Yield calculation based on: blocks with a height h≤60 mm give two boards, blocks with h>60 mm give three boards. Sawcut 3 mm and polishing loss 1 mm per surface.

CONCLUDING REMARKS AND FUTURE WORK

The Value Activation program has up to now shown that there are great possibilities of utilizing the properties of wood in a better way than our conventional wood production concepts can achieve. New wood products with desirable properties can be developed. Most of these products are expected to give an increased added value of the wood. The R&D-program will continue with the further development of improved products and also with the development of cost-efficient production systems for implementing the ideas from our R&D in profitable production units.
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