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PRODUCTION AND MATERIAL PERFORMANCE OF LONG – STRAND WOOD COMPOSITES

REVIEW

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ABSTRACT

In the last three decades a new group of engineered wood composites e.g. Scrimber, TimTek, Superposed Strand Timber, and Quetschholz has been developed. The basic idea of these wood composites was a new non-cutting technology to produce long strands with strict grain orientation. The strands were covered with glue, parallel aligned and pressed to high performance wood composites. This paper gives an overview of the different concepts of non-cutting strand production. In a second part of the paper the different products which have been produced from these long oriented strands will be presented. Comparing the properties of this new group of wood composites proves that they are able to compete with the mechanical performance and production costs of existing engineered wood products e.g. OSB (Oriented Strand Board), PSL (Parallel Strand Lumber) and, LSL (Laminated Strand Lumber). Despite the excellent mechanical properties the new group of wood composites show low dimensional stability which can mainly be attributed to the production of the strands.

KEY WORDS: engineered wood products, quetschholz, recombined wood product, scrimber, strands, superposed strand timber, TimTek

INTRODUCTION

Strand or particle geometry is one of the most important factors determining the properties of wood composite materials. In general, longer and thinner strands improve the mechanical properties by increasing more actual contact area and better stress transfer (Forintek 1999). On the other hand decreasing strand size leads to a low variability of the material properties. However, the homogeneous material properties of wood composites involve reduced strength and stiffness but also higher energy demand for cutting and gluing (Teischinger 2001).

The relationship between grain angle and strength and stiffness is well described for solid wood (Kollmann 1951, Eberhardsteiner 2002). Similar effects of grain orientation within the strands and of the strand orientation itself can be assumed for wood composites. Therefore the optimal grain orientation within the strands as well as the axial alignment of the strands has to be considered to describe and to optimize the mechanical properties of engineered wood composites.

Cutting is commonly used for the production of wood strands. However, the length of strands or chips is limited by the construction of flakers and the interaction between the cutting knife and the wood material (Uhmeier and Persson 1997). In order to produce longer and thinner strands rotary cut veneers are used as an intermediate product and cut into long (strands) sticks, as described in the Parallam® process (patents: US 4563237, US 4872544, WO 92/01541). However, the Parallam® process includes high costs due to several production steps e.g. log steaming, veneer peeling, drying and grading of veneer sheets and because of the raw material i.e. big diameter and peelable logs.

With respect to the changing politics in forestry the availability of big diameter, high quality round wood for sawn timber from natural forests have been limited in the last decades. On the other hand a high quantity of low grade small diameter round wood is now available from plantations (Jarck 2003). The basic idea of a new group of engineered wood composites was to produce long strands with a strict grain orientation from low grade softwoods. Due to stem taper, stem curvature, spiral grain and local fibre deviation in the vicinity of knots, the grain orientation within a strand is restricted by using common cutting technologies. In this sense low grade logs also mean low strand quality. Therefore, the utilization of these new cheap wood resources for optimized engineered wood products demanded new processing technologies.

The decomposition of wood without using rotary cutting technologies needs controlled crack propagation. Basically two different concepts of non cutting strand production were developed i.e. roll crusher and press plates technology. The basic principle of strand production with a roll crusher is to apply normal stresses in a gap between two counter rotating rollers (Clements and Puruthyan 2002, Oja 2004). Due to these normal stresses the log is flattened and the material is spread in the horizontal direction, which causes shear forces normal to the fibre direction i.e. rolling shear. Additionally the squeezed log is stressed in bending with the maximum bending moment in the gap between the two rollers. Corresponding to the curvature of the rollers the upper side of the log is bended upwards, whereas the lower side is bended downwards, which causes tensile stresses and splitting perpendicular to the grain in front of and behind the counter rollers. In contrast strand production by means of the press platen technology mainly induces compression stresses perpendicular to grain, which causes rolling shear stresses and material separation parallel to the grain.

In order to separate a whole log into strands several cycles of the roll crusher or press platen process are necessary. Between the cycles the distance between the two rollers has to be reduced. The end product is a mat of interconnected or single strands with optimal fibre orientation. The grade of strand separation and material deformation and destruction depends on several factors e.g. log length, profile of the rollers, number of cycles, etc. (Adachi et al. 2002).

In the following part different specific concepts, patents and the history of alternative strand production will be described. On the other hand production of the new wood strand composites will be presented and their mechanical properties will be compared to existing engineered wood products.

Harvey Jr. process

The first application of a roll crushing technology aiming at the separation of logs into longitudinal strand was invented by Harvey Jr. in Tennessee and patented in 1972 (US3674219). The process of Harvey Jr. uses a series of counter rotating rollers of a more or less uniform thickness. The first series of rollers has a disc-shaped profile to split the logs in the longitudinal direction. The second series of rollers is cylindrical to separate the material into smaller strands as described above (Fig. 1). The distance between the rollers decreases and can be vertically activated under controlled pressure of such magnitude as to cause the solid wood to separate into strands along the grain. After the roll crusher the material is pressed between pulsing press platen (scrubber) to separate the still interconnected strands (Fig. 1). The patent of Harvey (1972) participated the basic idea of all next patents concerning roll crusher and crushing between press plates. However, his patent was never translated into a technical process.

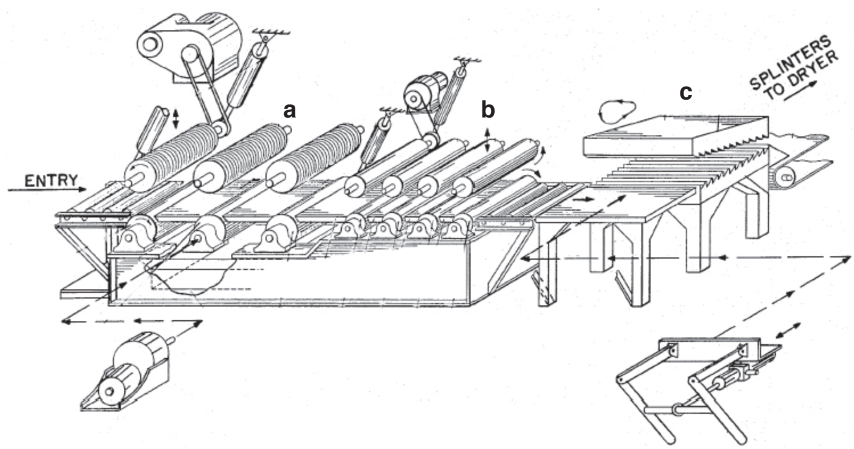

Fig. 1: Wood defibrating apparatus after Harvey, Jr. (patent US3674219). a – first series of crushing press-rollers, b – second series of crushing press rollers, c – scrubber for separate interconnected strands

Scrimber process (TimTek)

Independently a roll crusher process, as described in the patent of Harvey (1972) was developed by Coleman (1975) at the CSIRO, Australia (patent AU510845). The process of Coleman uses a series of rollers where the logs are flattened and split into strands (Fig. 2). The strands still interconnected are glued and compressed to beams which are called Srimber. In 1989 the first commercial plant was built in South Australia to use radiate pine thinnings (Sheriff 1988). After a "period of ups and downs" with defects of gluing, suitable quality of products and political problems the plant was closed in 1992 (Rutheford 1991, Jarck 2003).

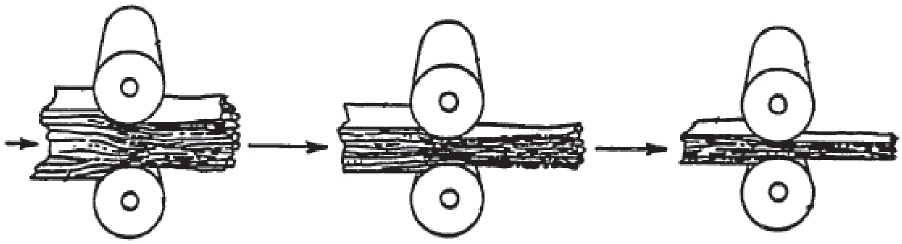

Fig. 2: Principles of original Scrimber production of blankets (interconnected strands) (Patent EP0414758)

A re-launch of the Scrimber technology was induced by cooperation between a financial consortium and the Mississippi State University (MSU) after a 20 years' break. The Scrimber technology was improved especially with respect to the gluing performance and a new trade name TimTek was introduced by the consortium. The pilot plant for the utilisation of thinning was opened in the Forest and Wildlife Research Centre of MSU in December 2003 (Sullivan 2003, Lipe and Sullivan 2004). In 2005 the Shuqualak Lumber Company bought a TimTek license and planed to build a TimTek engineered wood products plant in Meridian, US (Ann. 2005).

The process was originally developed for Eucalypt (*Eucalyptus pilularis*) and Radiata Pine (*Pinus radiata*) thinnings in the South of Australia (Hutchings and Leicester 1988). The Scrimber process utilizes more than 85% of the log (Jordan 1989). A commercial plant in the State of Mississippi using the TimTek technology is planned to utilize 15-year-old Loblolly Pines (*Pinus taeda*) thinnings (diameter from 75 – 200 mm) (Lipe and Sullivan 2004, Ann. 2004).

The main difference between the original Scrimber and the TimTek process is the improvement of the gluing and pressing technology. In the original Scrimber process the glue was cured by means of a radio-frequency press, however, the TimTek technology uses a steam-injection press (Jarck 2003)

Recombined wood composite (重组木)

Research activities in the field of the roll crusher technology were mentioned in the "Ninth Five-Year Plan" as well as in the "State Hi-tech Industry Demonstration Project Plan" in China (Ann. 2003). The Chinese name of this engineered wood product is 重组木, which can be translated into "recombined wood composite". The research centre of recombined wood composite is located at the Northeast Forestry University in Harbin (Yan 2004). The first pilot plant is located in Xuanhua in the province of Hebei close to Beijing and has been in operation since 1999 (Xingbo et al. 2001). The production is focused on boards with dimensions of 20 mm thickness and 1.2 m width and 2.4 m length respectively. Beside the production of boards the research group in China has also been focused on the production of beam elements for door frames or rail sleepers (Songling et al. 1999, Yan 2004).

Similar to the original Scrimber process of the CSIRO, Australia, the Chinese pilot plant produces mats of still interconnected strands ("Mushu"), which are directly used for the production of the engineered wood product. Hardwood (poplar) and softwood species (larch and pine) are primarily utilized for the Chinese recombined wood composite (Liping et al. 2002). The minimal yield of interconnected strands reaches 75%. The capacity of the pilot plant is designed for a production of app. 10,000 m^3 per year (Ann. 2).

Press-platen process (Quetschholz)

In the early 1970s a process called "Quetschholz" (squeeze wood) was invented at the University Of Applied Sciences in Eberswalde, in the former German Democratic Republic (Götze, Luthard 1974, Götze et al. 1980). Instead of a roll crusher the small-diameter logs are pressed (squeezed) between two inclined, pulsing press plates (Fig. 3). Basically the principle of the "Quetschholz" process corresponds to the "Scrubber" described in the patent of Harvey (1972) (Fig. 2). However, the "Quetscholz" process uses the pulsing press plates for the decomposition of the logs, whereas the "Scrubber" in the Harvey process was designed for the separation of interconnected strands after the roll crusher. The strands were produced in a separation-aggregate after squeezing, but a detailed description of this separation aggregate is neither given in the patent nor in any related literature. After adhesion application an oriented mat is formed and pressed to get a timber called "Quetschholz".

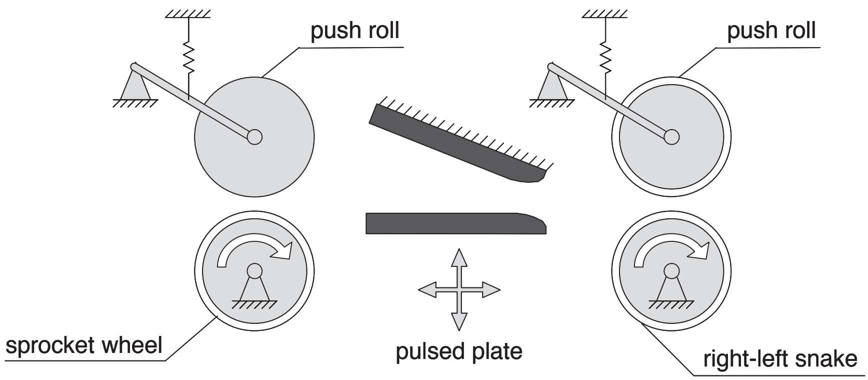

Fig. 3: Principles of the 'Quetschholz' production of strands (Patent DD112623)

Pine wood (*Pinus sylvestris*), but also spruce (*Picea abies*), beech (*Fagus sylvatica*) and oak (*Quercus* spp.) wood was used for the production of "Quetschholz". Due to the deconstruction of the wood structure during squeezing material failure of the composite beams takes place not only along the glue line between the strands but also along the earlywood – latewood boarder within the strands (Lehmann 1978, DD112623).

Because of different non specific issues "Quetschholz" was never produced in a commercial mill (Wiechel 1999).

Press-splitter process (Superposed Strand Timber)

Superposed Strand Timber (SST) was developed at the beginning of the nineties of the last century by Fujii and Miyatake at FFPRI in Japan (Hayashi 2000). In that process small diameter round wood thinnings or waste wood is processed to strands parallel to the grain. In that process the wood material is split by using a series of roll press-splitter into strands along the grain (Fig. 4). Each splitter has a pair of disc cutters of different shape and dimensions. The first splitter (distances between the cutters are 10 mm) splits logs into thin plates and the second splitter (distances are 4 mm) splits the thin plates into strands (patent EP0666155A1). The strand yield of the process reaches more than 90% in volume (Miyatake and Fujii 1997, Miyatake et al. 2000).

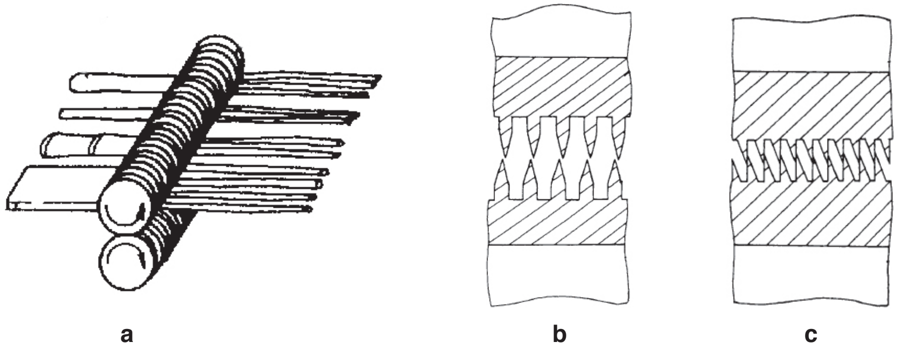

Fig. 4: Principles of splitting the wood logs and waste wood into long strands (a). First split-rolls for preparing thin wood plates (b) and the second split-rolls for producing strands (c) (Patent EP0666155A1)

Species with low density, small knots and straight fibre orientation are suitable for the strands production, such as Yanaka (*Salix* spp.) and Sugi (*Cryptomeria japonica*). The system can use whole logs, even if they are curved and bended (Miyatake 2004b). High density wood species or knotty logs are not process able because of the possible damage of the disk cutters.

An experimental pilot plant with a capacity of 7,500 m^3 per year had been in operation in Tsukuba next to Tokyo, Japan since 1997 (Hayashi 2000), but was closed after a few years because of economical troubles of the industry partner (Miyatake 2004a).

Board production

Generally the gluing and pressing technology of the new long-strand composites is quite similar to the production of other well known engineered wood products such as PSL (Parallel strand lumber), OSB (Oriented strand board), LSL (Laminated strand lumber). After crushing the strands or the still interconnected strands-mats are dried down to moisture content (MC) of 3 - 15% (Tab. 1). In the original Scrimber process (AU510845) as well as in the TimTek process (Jarck 2003) the dry strands are dipped into a glue basin for 5 to 20 seconds. In the "Quetschholz" process (Götze and Luthard 1974) as well as for the production of the Chinese recombined wood composite (Yan 2004) and in the SST process (Miyatake 2004b) the resin is sprayed onto the strands.

Tab. 1: Characteristics and technology data of long-strands composite material production

	units	Scrimber	TimTek	Quetschholz	SST	重组木
MC	%	5	-	6	3-15	2
glue content	%	5-12	10-12	10-20	5	8-10
Glue		UF/ TaninF	PF	PF (IC)	PF (IC)	Carbamid [A]
Press		RF platen-press	steam-injection	platen-press	steam press	platen-press
Pressure	MPa	up to 2,7	-	1,2	0,6-1	4-6
press temp.	°C	20-60	140	20	10-25	22
max. dimension (h,w,l)	mm	124x1200x12000	184x1219x1422	21x430x1000	12x750x4400	20x1200x2400
Density	kg/m³	540-670	688-720	700-750	460-660	880-930
MOR	N/mm²	6-9 [B]	14-17 [B]	60-85	58-81	30-80
MOE	N/mm²	9200-10800	8274-15858	10700-12000	7670-10820	5000-9000
Thickness Swelling	%	5-20	8-12	10-18	27-41	-
Source		Jordan 1989, Hutching & Lanceser 1988	Jarck 2003	Wiechel 1999, DD 112623	Miyatake & Fujii 1997	Liping et al. 2002, Xingbo 2001

[A] particleboard resin

[B] designed value (mean value not available)

The new wood strand composites are mainly bonded with phenol-formaldehyde - (PF) resins. On the other hand also urea-formaldehyde (UF) resin or tanin-formaldehyde (Tanin-F) resin was used in the original Scrimber process (Hutchings and Leicester 1988). For the production in the "Quetschholz" process (Wiechel 1999) and for the SST production isocyanate (IC) resins were applied to improve dimensional stability (Miyatake 2004a).

The mat formation is an important production step which has a strong influence on the strand orientation and therefore on the mechanical properties of the composite (Sasaki and Kawai 1994). Under labour conditions but also in the production process of the Chinese recombined wood composite the mats are formed by hand and strands are aligned into the longitudinal direction of the board. For further development of the production process of the long strand composites, automatic mat formation systems as used for the PSL or OSB production are needed (Forintek 1999).

Curing of the adhesives and pressing of the formed mat is usually done in a platen-press (Tab. 1). The research group at CSIRO, Australia, investigated different heating systems e.g. microwave, dielectric and live heat for the Scrimber production. However, the Scrimber pilot plant used a radio-frequency (RF) press (Hutchings and Leicester 1988). The steam-injection press was developed for the TimTek pilot plant in Mississippi, USA. In this process the press is placed into a steam tube. Before pressing, the strand material is heated up by means of the ambient steam. Then the press is closed and the resin is cured under steam at 140°C and a pressure of about 3.5 bar. By using the steam injection press the dimensional stability was improved (Jarck 2003). Additionally, the steam injection press allows the production of thick beams (Jarck 2003), which cannot be achieved by means of a conventional press. The main parameters concerning the gluing and pressing technology of the different long strand products are shown in Tab. 1.

The dimensions of the boards are only limited by the press equipment available. In the original Scrimber process a continuous press was used and the max length of the composite was up to 12 meter. In the labour condition a max length of 1 meter (Quetschholz) and 600 mm (SST) was produced, respectively (Tab. 1).

Board properties

The density of the long strand composites shows a high variability ranging from 450 kg/m^3 (SST, Japan) up to 900 kg/m^3 (recombined wood composite, China and "Quetschholz", Germany) (Tab. 1). In general density is an important factor influencing physical and mechanical properties of wood composites. The main parameters influencing the density and density profile of wood composites include: Moisture content, rate of press closure, temperature and pressure (Strickler 1959, Dunky and Niemz 2002). The pressure in the platen press varied from 0.4 N/mm^2 (Superposed strand timber) up to 2.7 N/mm^2 (original Scrimber process). The effect of density variation on the mechanical and physical properties of SST consisting of Yanagi strands (*Salix spp.*) was investigated by Miyatake and Fujii (1997). In this study the change of density from 460 kg/m^3 to 660 kg/m^3 caused an increase of MOR from 58 N/mm^2 to 81 N/mm^2 and an improved MOE from 7,670 N/mm^2 to 10,820 N/mm^2, respectively. Highly increased MOE values up to 12,000 N/mm^2 were observed for long-strand composites (Jarck 2003). This increased stiffness value corresponds to the relatively high density of the TimTek beams ranging from 688 to 720 kg/m^3. Even though the recombined wood composite from China shows high density values the MOE ranges from 5,000 to 9,000 N/mm^2 (Liping et al. 2002, Yan 2004). These low stiffness values can probably be attributed to the use of hardwood species for the strand production. In Tab. 1 the stiffness values of the different long strand composites are summarized.

On the other hand the increase of density also means an increase in thickness swelling. Beside the pressing technology also the production of the strands by means of a roll crusher or pulsing press platen influences the density of the long strand composites. As mentioned above the production process includes compression and deconstruction of the wood structure, and partly complete cells collapse. Under high moisture conditions, the damaged and collapsed cells tend to recover to their original shape and volume (Geimer et al. 1998). Depending on the density and the pre-damage of the wood material thickness swelling varied from 27% to 41% (Tab. 1). Higher values of thickness swelling of the original Scrimber and of the SST can be explained by the platen press technology. On the other hand the steam-injection press significantly improves the dimensional stability of the wood composite (Hse et al. 1995). In general, the use of isocyanate resins improves the mechanical properties and the dimensional stability of composite materials (Dunky et al. 2002).

The MOR depends on many factors, e.g. density profile across the composite, resin content as well as on the press technology used. MOR values of long strand composites are consistently higher by using conventional platen-press technology than by means of a steam-injection press (Hse et al. 1995). The glue content and therefore the sufficient bonding of strands is also an important factor affecting the bending strength of long strand composites (Engels 1983). For the Chinese recombined wood composite a modulus of rupture (MOR) between 30 – 80 N/mm^2 is given. Similar to the MOE also the MOR can be related to the board density ranging from 880 kg/m^3 to 930 kg/m^3 (Liping 2002, Yan 2004). The MOR values of long strand composites are summarized in Tab. 1.

Beside other technological parameters, strand length is also a very important factor influencing the mechanical properties of a wood composite (Forintek 1999). Typical strand length and MOE and MOR values of OSB (Krono Swiss), LSL, PSL (Trust Joist) and Eurostrip (SAB Bad Berleburg) were gained from literature. MOE values of these well known wood composites as well as of SST, Scrimber and TimTek beams were plotted over the strand length (Fig. 5). Independently from density variation strand length and MOE shows a strong correlation with a coefficient of determination R^2 = 0.73 (Fig. 5). Unfortunately only for SST mean values of both, strand length and MOR are available. Figure 6 shows a linear relationship between strand length and MOR for OSB, LSL and PSL. Whereas SST and Eurostrip show MOR values in the range of PSL even the strand length reaches only one third of PSL strands.

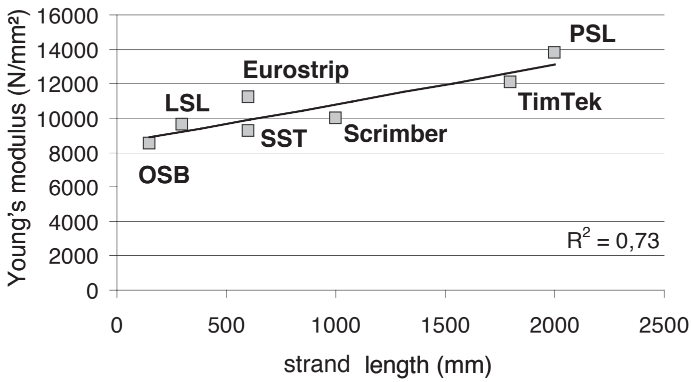

Fig. 5: Relationship between strands length and the Young's modulus by different wood based composite materials

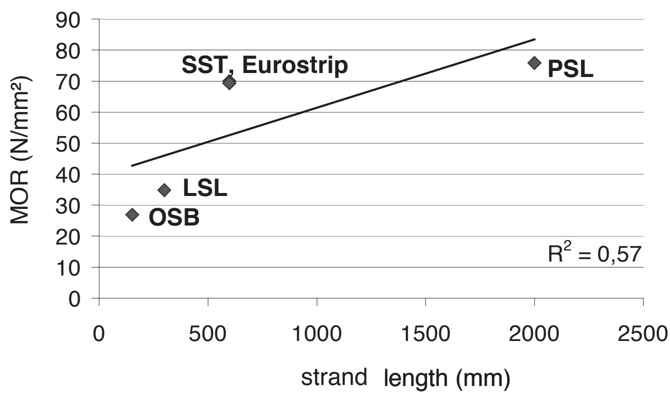

Fig. 6: Relationship between strands length and the bending strength by different wood based composite materials

Comparing the mechanical properties it could be shown that the group of long strand composites are competitive with well known wood composites i.e. OSB, LSL, PSL and Eurostrip. With respect to the raw material, the yield of the raw material, and production cost, the group of long strand composites shows clear advantages over the other engineered wood products. The reason why the roll crusher technology and related strand products did not reach production maturity can probably be related to low dimensional stability of these products.

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