ENGINEERED WOOD:
MANUFACTURING PROCESSES OPTIMIZE FIBER UTILIZATION & ENGINEERING PROPERTIES

Donald J. Sharp
Trus Joist MacMillan
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INTRODUCTION

There is no generally accepted definition of engineered wood, but wood structural members have been engineered in varying degrees for centuries. First was sawing timbers and boards from logs to better fill specific functions in structures. This was followed by visual grading, kiln drying, and precision sizing; all intended to make wood utilization more efficient. Machine stress rating of lumber was introduced around 1960, again, to more efficiently sort and utilize the resource.

More obvious examples of modern engineered wood are various forms of composite members like plywood, OSB, glued laminated beams, I-joists, and trusses. By engineering these products for specific uses, a considerable increase in efficient use of wood was achieved.

Current technology has produced a new family of engineered wood called "Structural Composite Lumber" (SCL). Present SCL products are Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), and Laminated Strand Lumber (LSL). This paper reviews these SCL products beginning with a brief history and the research and development process. This is followed by a general discussion of the manufacturing processes. The status of this industry and a brief discussion of various uses of the products is given.

It is appropriate here to note that all present SCL products, at least all those manufactured in commercial quantities, are proprietary. That is, each manufacturer has unique, and often patented, processes. Mechanical and physical properties vary over a considerable range. In North America, a consensus standard ASTM D5456 (Standard Specification for Evaluation of Structural Composite Lumber Products) has been completed which prescribes procedures for developing properties on a performance basis. Standards limited to LVL are being developed in Australia and Japan.

Because of the proprietary nature of SCL, details only on products manufactured by Trus Joist MacMillan can be provided, but an effort has been made to present this information in example form.

Trus Joist MacMillan is a partnership formed in 1991 between MacMillan Bloedel and Trus Joist Corporation. Trus Joist Corporation was devoted exclusively to the manufacture and marketing of Microllam™ LVL and TJI prefabricated wood I-joist and other engineered wood products. MacMillan Bloedel is a general forest products company located in Canada who had developed Parallam® PSL and Intrallam™

LSL. From the MB side, only the Parallam® and Intrallam™ plants and products were included in the partnership. Trus Joist Corporation provided an extensive marketing and engineering support organization and became the managing partner.

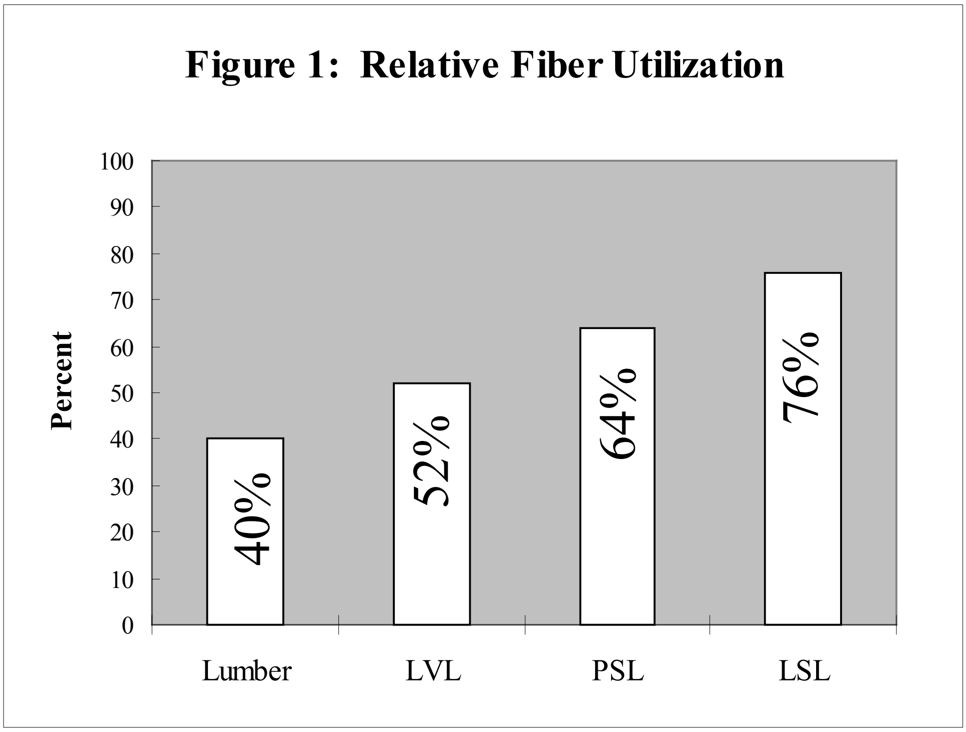
RESEARCH & DEVELOPMENT OF STRUCTURAL COMPOSITE LUMBERS

GENERAL CONSIDERATIONS:

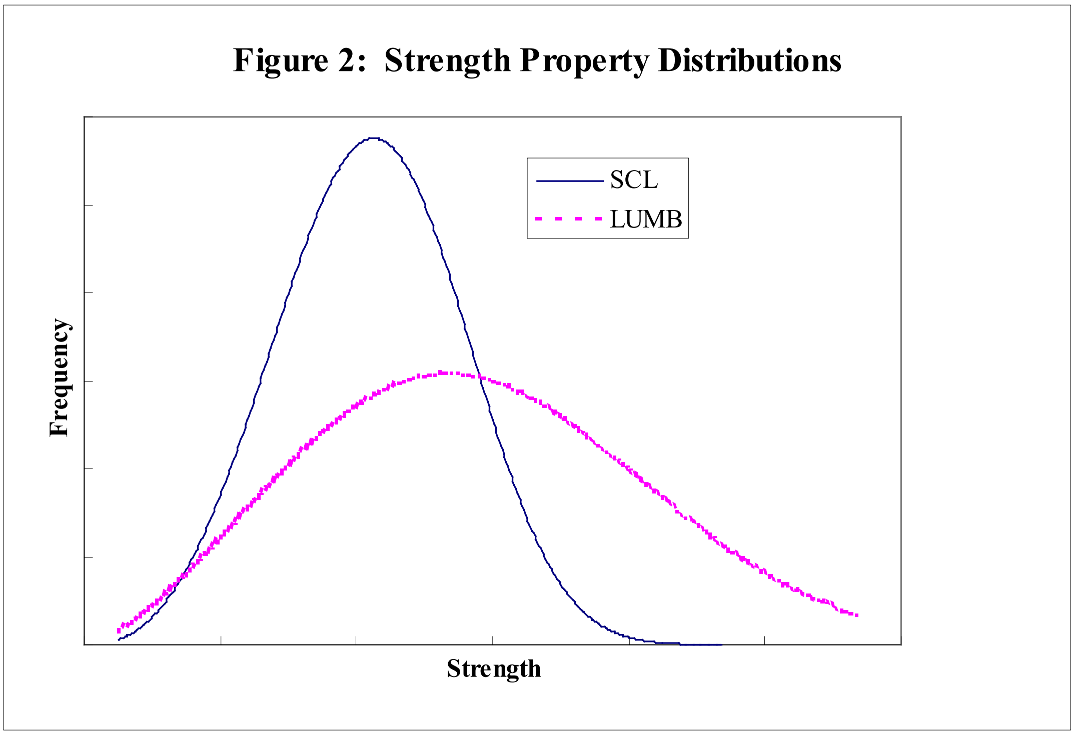
The fundamental concepts of research and development are quite simple. Research produces a vision of a product and the concepts of manufacturing, probably including some laboratory produced material. Development then refines the concepts and delivers the product to marketing complete with manufacturing facilities. In practice, of course, it is rarely so simple since economics must be considered at each step and many iterations can be required. This is particularly the case when new technology is being developed.

In each case of the research and development of SCL's there were two primary objectives: (1) to more efficiently utilize the fiber resource, and (2) at the same time, produce a more reliable and usable high-grade structural product. The first objective was prompted by a diminishing resource, at least of high quality, and a desire to reduce fiber waste and achieve greater economies. The second objective is a combination of engineering considerations and marketing requirements: It is clearly desirable to develop more reliable, and therefore safer, structural material. But since these products may have a higher unit cost than existing products, it is also necessary that they have value added attributes which fill market needs. It is not coincidence that these objectives also produce more environmentally correct products; proper engineering should always produce more efficient use of natural resources.

As an example of achieving the first objective, the relative log utilization of lumber and Trus Joist MacMillan products are shown in Figure 1. Microllam™ LVL was the earliest of these SCL's and the progressive increase in fiber utilization with the newer products is clearly evident.

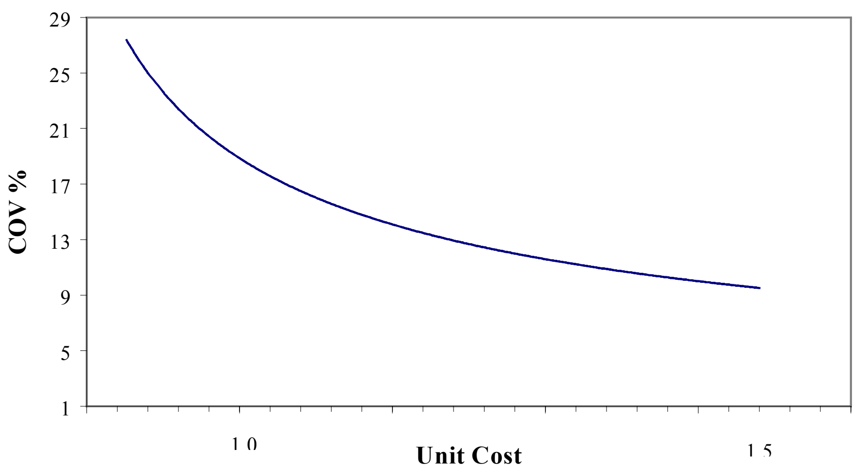


The second objective is partially depicted in Figure 2. This shows the type of strength distributions usually associated with SCL compared to that of sawn lumber. Some value added attributes are: Smaller section sizes due to higher stresses, longer lengths, and much greater dimensional accuracy. In varying degrees, it is also possible to adjust process parameters to produce the same properties using some range of species and log quality. A further value added feature is the possibility of customizing properties for particular applications.



It is possible to produce increasingly reliable materials with the introduction of more and more sophisticated process procedures and controls. This idea is shown graphically in Figure 3. Increasing reliability is represented by decreasing property COV, but this is accompanied by exponentially increasing cost. At some point in decreasing the COV it becomes necessary to begin eliminating part of the resource and using only the higher quality which progressively detracts from the first objective. Furthermore, a perfect material has no value if no one can afford to use it.

Figure 3: Reliability and Relative Cost



Each of the two primary objectives has many subdivisions which must all be continuously considered throughout the research and development procedure. If the initial concept is sound, eventually the product is developed and introduced to the market.

Quality assurance of these products is a topic which would require a separate paper to cover in detail, but it certainly deserves mention. It is extremely important, in these relatively complicated manufacturing processes, to establish appropriate quality assurance procedures during the development phase. Each key element in the process must be controlled to assure stability of property distributions. Structural testing of the finished product also needs to be done to check process controls.

RESEARCH AND DEVELOPMENT OF MICROLLAM™ LVL

In the 1960’s Trus Joist Corporation was a manufacturer and marketer of trusses, consisting of MSR lumber chords and tubular steel webs, with a unique pin connection. A considerable range of truss profiles and sizes was offered, including spans up to 35 meters. With the objective of creating more efficient chord material without finger joints and offering a greater range of chord size and improved reliability, the company research department conceived the idea of long length laminated veneer lumber.

LVL was not a particularly new idea: The idea of producing a more reliable wood member by statistically dispersing defects among many thin layers, probably had its origins in the aviation industry in the 1920's when most airplane structures were still wood. Some amount of research had been conducted by governmental and university laboratories as well as by private firms over following decades. In the late 1960's, however, no one had successfully commercialized an LVL product and the research had been limited to material made in small plywood presses.

During a period of approximately two years, Trus Joist Corporation developed a prototype press, capable of producing a billet of LVL approximately 600 mm wide, of varying thicknesses and of continuous length. In 1970, however, evaluation of the cost and value added features of the product concluded that it was uneconomical for the intended truss chord use.

In approximately the same time period, Trus Joist had developed a manufacturing process to mass produce pre-fabricated wood I-joists. This joist originally consisted of very high grade MSR lumber flanges and plywood web. This product gained immediate acceptance in the market place and by 1970 the supply of high grade MSR lumber for flanges was nearly exhausted. A re-evaluation of Microllam™ LVL concluded that this was an ideal material for I-joist flanges. In 1971, the first Microllam™ LVL plant was opened in Eugene, Oregon.

In the past 25 years, a considerable amount of research and development in the LVL process has continued. Probably most significant among these projects was the introduction in 1978 of ultra-sonic grading of veneer. This improved reliability, permitted the production of various grades, allowed utilizing different species, and increased fiber utilization.

RESEARCH AND DEVELOPMENT OF PARALLAM® PSL

In the 1970's MacMillan Bloedel Research conceived the idea of a manufactured strand lumber product. The concept was to reduce logs to strands, which would eliminate defects and still allow utilization of most of the logs. It was theorized that properties could be controlled by varying strand length and thickness and by adjusting product density. Furthermore, it was thought that such a process would permit the utilization of species not suitable for lumber and plywood. Laboratory work confirmed the general concepts.

The problems of developing the strand lumber concept to a commercially viable manufacturing facility were very great. Once the strands were produced, they had to be coated with resin and then reassembled in a consistent and uniform manner and conveyed to a press for curing. The basic press requirements were to produce a rectangular section of uniform density which could then be re-manufactured to finished sizes.

The strand handling requirements were fulfilled by a combination of belt and trough conveyors. A unique press was developed to MacMillan Bloedel Research specifications by Kusters in Germany. MacMillan Bloedel Research solved the uniform density requirements with microwave, which uniformly heats the entire section at the same time.

After 15 years of research and development and an expenditure of approximately 75 million dollars (Canadian) a prototype plant began producing Parallam® PSL in 1984. The raw material resource for this plant was Douglas fir veneer.

RESEARCH AND DEVELOPMENT OF INTRALLAM® LSL

While the research and development of Parallam® PSL had succeeded in producing a strand lumber, only part of the original objectives had been achieved. The properties of Parallam® PSL are still, to a degree, dependent on those of the raw material. That is, the objective of producing a high grade structural product from under utilized species had not succeeded.

MacMillan Bloedel had also been the industry leader in the development of waferboard and OSB using Aspen. Modifying the OSB process and borrowing from the long experiences of developing Parallam® PSL, a product originally called PSL 300 was developed.[1] While the manufacturing process for Intrallam® LSL is somewhat similar to that of OSB, the finished product is not. The strands are produced by flaking logs as in OSB, but the strand produced averages around 25 mm in width and 330 in length. This strand geometry is a key in producing controlled orientation in the process. To produce high grade structural product from low density species, it is necessary to uniformly densify the raw material. The steam injection pressing technology developed by Siemplekamp provided the solution.

Production trials were successfully conducted in Germany and construction began on a manufacturing plant.

The first Intrallam® LSL plant was put in production in 1991 in Deerwood, Minnesota. Species used are Aspen and small amount of similar low valued trees.

SCL INDUSTRY, MANUFACTURING PROCESSES AND USES

INDUSTRY

Currently there are seven producers of LVL in North America, one in Finland, one in Australia, and small quantities are produced in Japan. Trus Joist MacMillan has six plants, while most other producers have one. The present LVL industry capacity is estimated to be in excess of 1,000,000 cubic meters per year.

The only PSL being manufactured is Parallam® PSL produced in three North American plants by Trus Joist MacMillan. The capacity of these plants is in excess of 200,000 cubic meters per year. A somewhat similar Australian product called Scrimber is apparently no longer being produced.

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[1] The name was later changed to Intrallam® Laminated Strand Lumber (LSL) or TimberStrand® LSL in North America. The LSL name was applied to avoid confusion with Parallam® PSL, since while both are strand lumbers, the process and products are quite different.

Intrallam® LSL is currently manufactured in two plants in North America. Present capacity for this product exceeds 250,000 cubic meters.

The prefabricated wood I-joist is currently produced by 12 or 15 firms in North American and several in Europe that are similar in nature. The overall capacity of this industry is probably in excess of 200 million lineal meters per year. This industry is included here since the flanges are the largest use of LVL.

MANUFACTURING PROCESSES

This section is devoted specifically to the manufacturing of Trus Joist MacMillan products since, as noted, all processes are proprietary. A general concept of four manufacturing processes is shown in Figure 4. A few comments on the various procedures for manufacturing LVL can be offered: Trus Joist MacMillan presses are a continuous tractor type. Presses manufactured in Finland can also produce a continuous product, but the process is more in the nature of a step-wise or staged procedure. Other manufacturers use large fixed presses. One producer manufactures first a plywood size panel and then in a secondary operation, end and face glues to produce the finished LVL in any thickness and length.

<u>Microllam™ LVL</u> The process begins with peeling and drying of veneer. Currently, most Trus Joist MacMillan production utilizes either Douglas fir or southern pine. Lodgepole pine and yellow poplar are also occasionally used. Other species are sometimes used for specialty products. Veneer thicknesses from 2.5 to 4.7 mm are used.

After drying, each sheet of veneer is visually inspected for conformance to established standards and then non-destructively tested and sorted into grades. The number and range of grades depend on the product to be produced. Grades can be adjusted to produce product with an manufactured stiffnesses anywhere from 10,000 to 17,000 N/mm^2.

The veneers are curtain coated with resin on one side and fed into the continuous presses in a pattern by grade, depending on the product being produced. Adhesive used is phenol formaldehyde. Specific formulations are provided for the spreading equipment and cure environment. Slight modifications are made by species.

The material is cured in a controlled environment of pressure, temperature, and time. The resulting product is a billet, either 600 or 1200 mm in width with thicknesses ranging from 19 through 89 mm. The billets are then ripped to the size required by the particular application.

<u>Parallam® PSL</u> The process also starts with peeling and drying of veneer, but full width sheets are not necessary. Stacks of veneer are brought to multiple lines where they are fed through clippers that produce strands averaging approximately 15 mm in width. The strands are fed through roll coaters that spread adhesive on both sides and are then delivered in a prescribed way to a moving trough where the required mat is developed. Each strand line contains short strand eliminators and the amount of material moving on each line is continuously monitored and line speeds adjusted to deliver a uniform mass to the press.

The adhesive used in Parallam® PSL is phenol formaldehyde mixed with wax, which enhances the stability of the finished product.

The finished Parallam® PSL billet has maximum dimensions of 285 x 480 mm. Presently, most production utilizes Douglas fir or southern pine, but production using Western Hemlock and yellow poplar has begun and other species are possible. By regulating density, manufactured stiffness of Parallam® PSL can be adjusted between approximately 12,000 and 16,000 N/mm^2.

<u>Intrallam® LSL</u> In this case, the logs are flaked rather than peeled and the entire log is processed. The strands are accumulated green in a storage bin and fed into the line on demand. Strands are dried in drum dryers and conveyed to dry storage bins where short strands are eliminated. Bark, short strands and other residues are conveyed to a boiler, which provides all the heat energy for the plant.

From the dry bins, strands are conveyed to the glue room where adhesives, wax and preservatives, when required, are applied in blenders.

The adhesive used in Intrallam® LSL is MDI, which is a form of isocynate based resin (polyurethane). This adhesive was developed by Bayer.

After coating with adhesive, the strands are conveyed to four forming lines where they are run through orientors to provide appropriate alignment and a mat of the prescribed mass is developed and fed into the press after cutting to a 10.7 m length. The press closes in a precisely regulated sequence of opening and pressure while the mat is heated by steam injection. After full curing, the finished billet exits the press and is trimmed to the final size of 2.4 x 10.7 meters.

Billet thicknesses ranging from 25 to 100 mm are possible. The billet can then be sanded to precise thickness tolerances and ripped to the desired member sizes.

Intrallam® LSL is manufactured from Aspen (a small amount of maple and birch is sometimes mixed in), which is rarely used in structures. Aspen is a rapid growth self-regenerating poplar with a 40-50 year life cycle. It is a wide spread species in cool climates across northern US states and southern Canada. The second plant uses yellow poplar, a widely available under-utilized southeast states species.

By adjusting the manufacturing process, stiffness grades ranging from 8000-12000 N/mm^2 can now be produced.

<u>TJI® Joist</u> Although a small percentage of TJI® joists (a trade name is Silent Floor® Joists) uses finger-jointed MSR lumber floor flanges, most use either Douglas fir or southern pine Microllam™ LVL. The uniformity of the Microllam™ LVL flanges helps assure consistent quality and permits greater manufacturing speed. Other manufacturers have developed similar processes.

Some plywood is used for the web, but most production now is with Performance Plus™ OSB. This is not a standard commodity OSB panel: The panels are produced under special contract with suppliers, to Trus Joist MacMillan specifications, which require greater strength and durability than usual. Presently Performance Plus panels are manufactured from aspen flakes with a combination of isocynates and phenol formaldehyde resins, or from southern pine flakes and phenol formaldehyde.

The manufacturing process is shown in Figure 4. Flanges are ripped to required width and routed. Panels are ripped and machined; precise tolerances between panel edge and flange rout are required. Web panels have machined joints at their junction in the web of the joist.

The joists are manufactured in a continuous process (length is limited only by practical handling length of the flanges). Adhesive used in the assembly of the joists is phenol resorcinol formaldehyde; joints are cured in an oven.

USE AND AVAILABILITY

Large volumes of Microllam™ LVL and other LVL's are used as TJI® joist flanges and as light beam members in building construction. Significant quantity is consumed as scaffold planks. It has been used in such diverse applications as diving boards and ski cores and in one case, was used as chords in a trussed barrel arch spanning 120 meters.

Parallam® PSL is used extensively as beams, columns, and in timber trusses. Many users are pleased with its unique appearance and it is often used in exposed applications.

Intrallam® LSL has been used very extensively in a wide range of industrial applications. Rails for windows and doors are common, as is table tops. It is a popular material in trade show booths. Structurally it is used in a variety of ways, which are just now emerging. A small quantity is being used as TJI® joist flanges and for small beams. It is used in rigid frames in agricultural buildings in France. It has also been used as the skin in stiffened tied arches in Austrian roof structures.

The most wide spread use of TJI® joist is in floors. They are also commonly used as roof members. Occasionally they have been used as stud members in tall walls.

In Germany see Deutsches Institut für Bautechnik certification Z-9.1-245 for Microllam™ LVL, Z-9.1-241 for Parallam® PSL, and Z-9.1-277 for TJI® joist. Work has begun on a report for Intrallam® LSL. These products are certified for use in France, UK, Japan, and Australia, and, of course, in North America. Other manufacturers should be contacted to obtain their current report numbers.

CONCLUSIONS

This brief paper is intended to provide an overview of a few modern technologies being applied to production of wood based structural members. Although the cost of research and development can be high, market success has demonstrated economic viability.

There can be little doubt that the future will see even more intensely engineered products. Such products will likely move closer towards the utilization of the properties of basic wood fibers. This increasing utilization of our natural resources will, of course, be an even more environmentally friendly solution in future structures.

Figure 4

Process Illustrations