AN OVERVIEW OF STRUCTURAL PANELS AND STRUCTURAL COMPOSITE PRODUCTS

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ABSTRACT

Plywood has been the principal structural panel for construction since the late 1940's. Today, structural panels are evolving into products such as composite panels, oriented strand board, waferboard and structural particleboard. While plywood will be the mainstay of production for some time, newer production facilities tend to be of other product types. Performance standards provide an opportunity to evaluate all of these product types under a common set of requirements. Research efforts to characterize these products is under way by the American Plywood Association in an effort to expend markets for panel products. Structural lumber substitutes and configurations of these products in beams have significant potential in future markets.

INTRODUCTION

The objective of this paper is to review the status of structural panel products and to identify in a general way the technical state of the art. Other structural composites manufactured with the technology similar to that of structural panels will also be briefly considered. Research efforts covering manufacturing technology have been omitted. This paper sets the stage for discussions which took place at the workshop on Structural Wood Research which was held in Milwaukee, Wisconsin in October, 1983.

STRUCTURAL PANELS

The structural wood panel products industry's primary market is the light-frame construction industry. For the past three decades it has supplied panel products to suppliers and contractors for on-site assembly of residential and commercial structures. The wood panels are long lived, durable goods which are commodities manufactured and distributed in standard sizes and grades.

Following World War II, plywood was utilized in light-frame construction in ever increasing volume. Much of this increased use can be attributed to research and promotion by the American Plywood Association (then Douglas Fir Plywood Association), as well as the technical work of the Forest Products Laboratory, and several universities providing proper engineering information to users and regulators alike. Because of sound research information, and the flexibility of panels in construction use, plywood displaced

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lumber as the dominant sheathing material for floor, wall and roof construction.

In recent years (mid-1970's), new generations of structural panels began to emerge. To better understand the nature of this revolutionary change, a look at the products, standards and their technology seems to be in order.

**The Products**

Structural panel products include plywood, oriented strand board, waferboard, COMPLY®, and structural particleboard. Each product is discussed briefly, reviewing the raw material resource and basic product structure. The products listed are in alphabetical order.

**COMPLY®**. Since 1976 several manufacturers have produced COMPLY®, which features face veneers bonded to a structural wood core consisting of oriented strands or random particle/flakes. On the surface the product looks much like plywood because the veneer used for the face and back is identical to that used in standard plywood production. While plywood utilizes veneer in its interior laminations, COMPLY utilizes structural composite boards made from strands, flakes or wafers. Cross alignment of the particle core considerably enhances overall panel dimensional stability and improves cross-panel strength and stiffness.

The panel manufacturing procedures used are either a one- or two-step process. In a one-step process where the wood particles composing the core are laid directly on the bottom veneer sheets, the top sheets are then placed on top and the entire panel pressed in a single-step operation. In a two-step manufacturing process, the core is made separately and transferred to a conventional plywood plant for processing to the finished composite product.

At one time, five composite plants were producing panels. As of the first quarter 1983, only two of these panel plants were operating, and at considerably reduced capacities. No further announcements or planned construction is known at the time of writing.

**Oriented Strand Board.** Oriented strand board (OSB) is a panel product composed of three to five layers of strands or rectangular shaped flakes which are typically three to five times longer than they are wide. Strands are produced (by a variety of flaking machines) from roundwood, which are logs transferred directly from the forest.

The product gets its name from the fact that the strands are oriented, that is, strands within a layer are aligned in the same general direction. Each layer is oriented perpendicular to the next.

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much as the veneers in plywood are perpendicular to one another in alternating layers. Strand alignment on the faces is typically parallel to the long or 8-foot direction, with cross-alignment of one or more layers in the interior of the product.

Orientation is perceived to provide considerable product flexibility in that it may be designed with stiffness and strength characteristics in particular panel directions.

Oriented strand board is manufactured with liquid phenolic resin and wax applied just prior to pressing. The use of liquid phenolic resin results in a slightly darker appearance to the board, and the strand or rectangular wafer geometry provides a somewhat different surface appearance than other flakeboard products.

There are currently six OSB plants in production as of the first quarter 1903, with several others pending.

Particleboard. Particleboards differ from other structural products, such as waferboard or OSB, in that the raw material source is the residue of other solid wood processing operations. Consequently, the particles from which the board is manufactured tend to be very small and have very little fiber length. Some of these products can be used structurally in light frame construction. Such products typically will gain their additional strength and stiffness from either higher resin content, and/or additional product thickness along with increased density. Because of the resulting cost differential, the percentage of products manufactured under these constraints is very small. One plant was producing such a product in the first quarter of 1983.

Plywood. The first production runs of softwood plywood took place on the U.S. west coast in the early 1900's. Production capacity continued to increase on the west coast until the early 1960's when southern pine plywood was introduced. Currently, nearly half the construction plywood industry (capacity basis) exists in the southeastern United States with the remaining plants in the Inland Empire and west coast of the United States.

Plywood is produced from veneers which are laid up in alternate layers, with each layer perpendicular to the other. By altering veneer thickness, ply orientation and species, plywood has demonstrated considerable versatility in being useful for a wide variety of industrial and residential construction market areas. Continuing research over the past 20 years has enabled plywood to enter many diversified markets, primarily due to a sound data base. Now about 62% of plywood markets are tied directly to new residential construction, or construction activities associated with repair and remodeling. The remaining material finds its way into a variety of end uses such as products made for sale, materials handling, plant repair and maintenance, and the transportation market. Additional uses include concrete forming, farm buildings, and a wide variety of miscellaneous applications. As of the first quarter 1983, approximately 170 individual plywood mills were producing. Their total in-plant capacity exceeds 20 billion square feet on a 3/8” basis.
Wafferboard. Waferboard is a structural use panel first produced in Canada in 1966. Since then it has spread to several Canadian and U.S. manufacturing locations. Plant locations, as for OSB, are taking advantage of low raw material costs in central and eastern Canada, and central and upper midwestern U.S.

Waferboard is generally manufactured from low density hardwoods (most predominantly aspen), although other manufacturers are considering the utilization of spruce, southern pine and western softwoods.

The product is composed of rather large, square (2" x 2" to 3-1/2" x 3-1/2") wafers. These wafers are flaked from roundwood and generally bonded together with a powdered phenolic resin.

Waferboards are typically produced in three random layers with the largest flakes, possessing the best mechanical properties, laid on the faces of the panel. The fines and other smaller flakes are utilized as core material. More recently, some manufacturers have begun orientation of the panel faces using more rectangular wafers -- thus approaching the OSB concept.

As of the first quarter 1983, five waferboard plants existed in the continental United States, and there were seven in the Canadian provinces.

STANDARDS

Product Standards

Historical standards, against which wood-based panel products have been manufactured, have been product standards such as PS 1-83 for Construction and Industrial Plywood, or ANSI 208.1 for Mat-Formed Wood Particleboard. National consensus or product standards are most frequently promulgated through organizations such as the American National Standards Institute (ANSI) or, in the case of U.S. Product Standards, the Department of Commerce. Recently the Department of Commerce has indicated they will be phasing out sponsorship of the voluntary standards, and consequently the only consensus groups left will be ANSI or the standards-making processes of the American Society for Testing and Materials (ASTM).

Review of product or commodity standards reveal that they are essentially manufacturing prescriptions for the minimum product. Requirements are centered around the specific manufacturing process, and typically do not address the question of product application nor how well the product is suited for any particular application.

Performance Standards

A performance standard, such as that promulgated by the American Plywood Association for APA Rated Sheathing and APA Rated Sturd-I-Floor, reverses the standards process by defining the end use of the product, and does not prescribe how the product will be
made. The objective of a performance standard is to assure, for a particular end use, that the product will satisfy the requirements of the application for which it is intended. To do this the performance standard must define performance criteria and test methods.

In the case of the two standards currently promulgated by APA, that for single layer floors (APA Rated Sturd-I-Floor) and that for sheathing (APA Rated Sheathing), the intended end use is light-frame wood construction as practiced in the United States. As the name implies, panels are intended for combination subfloor underlayment and sheathing intended for roofs, walls and subfloors. These products are span rated for their particular end use. The standards cover supports spaced 16" to 48" o.c. (406 to 1220 mm) for floors and roofs. Provisions are also made for wall bracing when the studs (vertical framing elements) are spaced 16" or 24" (406 or 610 mm).

Requirements. Panel performance is evaluated through testing under a qualification procedure for three basic areas of investigation: structural adequacy, dimensional stability, and bond performance.

Testing for structural adequacy includes:

1. Verification of the ability of the panel to sustain concentrated loads, both static and following impact.
2. Uniform loads testing to demonstrate the ability of the product to sustain wind or snow loads.
3. Fastener holding ability is tested to assure the panel has the ability to hold covering materials in place, and to develop lateral load capability in mechanically fastened connections to lumber or other framing.
4. Wall sheathing panels must demonstrate shear resistance for wall bracing.

Physical properties include the measure of panel expansion when exposed to moisture conditions. Two methods of linear expansion have been developed. The oven-dry vacuum-pressure-soak technique is adequate for quality control purposes, but does not reflect field conditions. Accordingly, a performance test was developed which measures linear expansion when wetting on one side for a period of 14 days. This test approximates severe exposure conditions as might occur during construction, and should serve as a relative measure of linear expansion conditions that might be expected in service.

Finally, the bond durability of the panel must be demonstrated for site-built construction, since panels will be called upon to resist wetting and drying and still be able to perform following exposure in these conditions. Results of extensive research have indicated that large-scale specimens exposed to hot water soaking and oven drying, and then subjected to the same structural performance criteria is adequate evidence of the ability of the product to remain intact during exposure to weathering. These tests are equivalent to several years permanent exposure to the weather. Retention of strength following moisture cycling is also used as a measure of bond performance.
Qualification. Certification of performance is a straightforward procedure under a performance-based system. To begin, a sampling of the candidate product is tested according to the individual performance criteria previously discussed. After demonstrating adequate structural performance, physical properties and bond durability, a span rating can then be assigned.

Concurrent with performance-oriented tests, a "product evaluation" is also performed. Product evaluation provides for measuring properties unique to the product and suitable for quality assurance measurements. Such data include bending strength and stiffness, thickness, density, and other manufacturing data which may prove useful in monitoring quality under a third-party basis.

A mill specification is drawn up following this intensive product evaluation. The individualized mill production specification is unique to the mill and product qualified under the performance standard. It pertains only to the mill and product qualified, and is not a constraint on other mills or similar products.

The mill specification serves as the quality assurance document for future evaluation. The APA quality program provides for sampling from each mill's production each day, with testing and reporting at one of seven regional facilities. In addition, a quarterly sampling program requires ten 4x8 ft. panels (1.2x2.4 m) per mill per quarter to be shipped to the APA Research Center in Tacoma. These panels are tested for conformance to the mill specification and will form the data base discussed later in this paper.

Acceptance. The Council of American Building Officials (CABO) is a joint venture of the Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International (SBCC). CABO has recognized the APA Performance Standards under their National Research Report NRB-108. The report constitutes approval by the sponsoring model code agencies, and subsequent regional acceptances have since been secured by the APA technical staff.

The acceptance of the performance standards concept by the plywood, OSB, and waferboard industry has been exceptional. In the case of plywood, the performance opportunities have been significant and are reflected by the fact that over 390 individual panel qualifications have been completed by the APA since 1980. In addition, over 40 approvals for waferboard and OSB have also been granted. It is estimated that approximately 80% of the total sheathing production of the United States is now being produced under the performance-rated concept.

The most recent edition of the Voluntary Product Standard PS 1-83 includes provisions for certain attributes of the performance-based concept.
The evolutionary change in development of new structural use panel products has called for a redoubling of technical effort to supply data for the myriad of other structural-use panel applications.

**STRUCTURAL TECHNOLOGY**

The increasing importance of the performance standards as a basis for product acceptance brings new challenge to the development of technical information suitable for making end-use recommendations beyond those specifically covered by the performance standards. As product volume increases under the performance standard, a corresponding need arises for technical information about those products.

**Product Characterization.**

In anticipation of the need for new technical data, APA has been conducting a significant product characterization study. This study being completed under the provisions of the performance standard, will lead to development of significant technical data on the character of products produced by APA members under these standards. The program covers sampling, mechanical properties, physical properties, and data base management.

Panel Sampling. Sampling of a product occurs at two stages. First, during the product qualification stage previously discussed, a significant sample of a product is taken under carefully supervised conditions. That is, the panel product is sampled at minimum manufacturing conditions such that minimum acceptable performance is evaluated. This initial bias provides a measure of minimum product against the performance criteria, and is an indication of minimum lot performance. Products which satisfy the established performance criteria under these conditions are certified for production at manufacturing specifications at or above the levels sampled. Thus, the data leading to the development of the individual product manufacturing specifications become the baseline for future evaluation of the product.

The second level of data collection is a quarterly production sampling program. Under provisions of the performance standard, a minimum of 10 panels per plant per quarter are tested by APA against the product's individual manufacturing specification. This evaluation provides an ongoing measure of product performance and continuing confirmation that the products are conforming to the provisions of the performance standard.

The panel sampling plan provides two significant opportunities. First, the initial biased sample provides an opportunity to evaluate minimum lot performance, and is a snapshot of minimum product performance as produced by individual mills, and products distributed over the country. Second, the quarterly sampling program provides an ongoing evaluation of products "as produced" and can then be used to establish any trends in product performance.
Mechanical Properties. Panels sampled under the performance-rated panel program are full-sized 4x8 ft. panels (1.2x2.4 m). Properties collected under both the qualification or initial bias sample scheme and ongoing quarterly sampling include the following:

- Full-sized panel bending strength and stiffness.
- Tensile strength.
- Shear strength through the thickness.
- Shear strength in the plane of the panel.
- Compression strength along the panel face.
- Compression strength across the panel face.
- Bearing strength through the thickness.
- Plate modulus of rigidity.

Each of these basic mechanical properties are collected with stress along and across the face of the panel when appropriate. Panels are tested in the dry as received condition, and provide a significant laboratory base for the mechanical performance of products produced under the performance standard.

Physical Properties. Specimens collected from the initial and quarterly sampling programs are subjected to the following evaluations:

- Linear expansion and thickness swelling from oven-dry to vacuum-pressure soak.
- Linear expansion and thickness swelling from 50% to 90% relative humidity conditions.
- Water vapor permeance.

Again, properties are evaluated both along and across the face direction when appropriate. Other potential physical properties evaluations include thermal expansion and electrical resistivity, and other properties which may be required in specific applications conditions.

Data Base Management. To accommodate such a comprehensive sampling plan, encompassing a large number of products, constructions and geographic manufacturing regions of the country, a sophisticated computer data base management system is utilized. Data base management schemes are most often firmware- and software-based systems which provide for easy assemblage of complicated data schemes providing for quick ad hoc reporting, as well as routine data manipulation and updating.

The computer-base data system then is utilized for ongoing evaluation of quarterly sampling programs via control chart and statistical analysis schemes, as well as providing overall statistical analysis of mechanical and physical property data as collected.

Reliability-Based Design. Reliability-based design (RBD) methodology is beginning to appear in the United States as well as other parts of the world. In particular, RBD procedures for steel
and concrete building structures have been developed in the U.S., Canada and Europe. It is reasonably certain that the structural design community is moving toward adoption of the RBD methods, and these moves could have impact on the structural panel business.

Reliability-based methods involve several key features. Primarily through the definition of the serviceability and strength limit states, and the recognition of the statistical nature of structural loads, the reliability of the system can be determined assuming that the system resistances or, for the purposes of this paper, the resistance capabilities of the structural product are known.

For structural systems requiring single member action of structural panel products, which must perform outside the limitations of the performance-based standards, the consideration of reliability-based design format seems appropriate. Clearly, the product characterization study under way by APA provides a base for product performance both at its minimum levels and as produced. These data will then provide the statistical distributions such as means, coefficients of variations, and types of probability density functions that occur for the various material properties. With the completion of these baseline data, opportunities exist for the use of computer simulation techniques to further enhance our understanding of the material resistance data for structural panel products.

The opportunities, then, for a reliability-based design format are significant in that a standardized code format may be available which all trained engineers would be used to, as well as provide for fundamental decisions to be made by the engineer, based on the reliability of the structural and the cost/benefit for the type of structure under design. Clearly, the reliability of a utility type structure does not need to approach that of a hospital. With this knowledge in hand, there should certainly be cost benefits in assessing a design or assigning those reliabilities in conjunction with local building code requirements.

Factors Influencing Engineering Design Properties

A product characterization study will provide insight to performance of products as produced and tested under laboratory conditions. Clearly, there is a myriad of factors which influence the performance of mechanical properties and, consequently, structural design. A few of the most important structural properties will be addressed here in the hopes of stimulating thought toward solutions.

In-Service Performance. A variety of techniques have been used to address the in-service load performance of wood structural systems. These include creep studies, creep rupture, studies, and evaluation of product after long-term in-service use. Given the time-consuming factors of creep and creep-rupture studies, it appears that some potential alternative means to identify the
performance of these products is needed. In conjunction with that, a North American duration of load committee of interested industry principals has been established in cooperation with the Forest Products Laboratory in Madison, Wisconsin and Forintek's western lab. These deliberations may provide a structured approach to providing short-term conservative answers and the development of data which will give us longer term information.

Environmental Effects. A variety of environmental factors must be assessed and their influence determined. Such areas include moisture effects, temperature, corrosive chemical environments and the like. A priorities list needs to be developed and assessed so these factors may be included in any design format.

Fasteners. Standardized methods of fastener evaluation for both lateral load-slip modulus and ultimate lateral loads need to be established. With significant variations in fastener size and stock stiffness, better methods of grading and identification are needed for engineering design.

Effect of Treatments. Little data exist on the effect of pressure treatments for preservatives and fire retardants on mechanical properties of structural-use panel products. Basic impact of these procedures is needed since the volume of material treated continues to grow.

STRUCTURAL PRODUCTS

Previous sections have described the evolutionary changes taking place in the structural-use panel business. As we look forward another 5 to 10 years, similar changes utilizing variations of these manufacturing technologies provide considerable promise for increased structural products.

One can visualize converting a variety of raw material types into products which have been designed for particular end uses. The basic element for reconstituted wood materials may be the fiber, as in paper, or it may be composed of many fibers, varying in size and geometry. These two factors, size and geometry, with their infinitely controllable variations, provide the chief means by which materials scientists can compose a material having Predetermined properties.

Large scale structural panels are already used to simplify the construction of roof and floor systems, and it is possible to imagine pressing not only flat sheets for decking but molded structural systems with integral geometries designed to fit into such specific applications. Improvements in material configurations are possible. Evolution of waferboard into OSB, resulting in nearly doubling the flexural strength with no penalty in other properties, represents a step in that direction. Lumber-like products are possible. Panels containing flakes oriented in predetermined configurations so as to yield desired material properties at lowest produced cost offer goals for the industry.
Important objectives for researchers are to improve the efficiency of utilization of increasingly expensive synthetic adhesives and to make better use of the inherent properties of wood in reconstituted panels. The reconstitution process by its nature breaks down wood’s native internal bonding, and retrieval of the inherent properties of the species used requires addition of sizeable amounts of adhesive and densification well beyond the density of the species itself. Ways must be found to mitigate this shortcoming. Other worthwhile goals are to more fully understand product/process synergisms leading to the capture of benefits from that understanding, and to the study of wood/non-wood combinations.

Our purpose here is to note the existence of and the potential coming of these products in commodity volumes from manufacturing facilities very similar to those for structural panel products. These products can be broken down into two basic groups, that of structural lumber substitutes, and structural composite components.

**Structural Lumber Substitutes**

Structural lumber substitutes under consideration include laminated veneer lumber (LVL), composite joists, and parallel strand lumber.

Since the late 1950’s a variety of researchers have reported on various “super strength” beams manufactured from rotary peeled veneer. The products have come to be known as parallel laminated veneer (PLV) or laminated veneer lumber (LVL). Generally, the products are manufactured from continuously laminating rotary peeled veneer into panels in which all the veneer sheets are oriented in the same direction. The economics of these structural products is exemplified by the significant manufacturing facilities operated by the Trus Joist Corporation of Boise, Idaho.

Primary advantages of LVL are the dispersion of defects by utilizing veneer, and the attainment of very high stress levels consistent with the highest grades of solid sawn lumber.

Composite studs and planks have been prepared utilizing structural particleboard cores and veneers to produce lumber substitutes. Again, the basic components are derived from structural panel plants, and have the advantages of consistent strength and stiffness in unlimited lengths and sizes.

Another more recent proposal has been to produce structural lumber substitutes using parallel strand lumber (PSL). Such schemes would develop cross sections in a continuous process using strands developed either from veneer or other processes utilizing round wood as the basic raw material source. Again, the perceived advantages are unlimited sizes and lengths, consistent properties and very high mechanical properties.

To meet the need of impending production approaching commodity levels, two standards for laminated veneer lumber have been
developed. The first is by the American Institute of Timber Construction (AITC) based in Englewood, Colorado, which provides for LVL as a substitute for tension laminates. This standard, AITC 402, is contained in the AITC Inspection Manual. Another more generalized approach for LVL is a draft standard under development by the American Plywood Association. The APA standard has taken the performance approach and will provide for trademarking based on the mechanical capabilities of the LVL. This standard will be available after review by the industry standards committee.

Structural Composite Components

A natural development stemming from new structural panel products and structural lumber substitutes is the combination of these products into various components.

Of noteworthy consideration is the I-shaped beam using structural lumber substitutes in the flanges and structural panel products in the webs. Trus Joist Corporation has had significant production of these beams for many years. Additional manufacturers are now joining in the production of these I-shaped composite products. The apparent advantage of these products is that they are light in weight, unlimited in length, dimensionally stable, and an economically viable alternative to solid-sawn products.

With increasing production, a group of the panel-webbed I-beam producers has been meeting to develop an industry standard which will allow for the rational development and marketing of a variety of cross sectional shapes and sizes. These structural components should find their way into many flooring and roofing systems.

SUMMARY

Since the 1950's, plywood has been the primary structural panel product for use in sheathing of floors, roofs and walls. Its use in a variety of industrial and engineered structural applications is the direct result of significant research over the past 25 years.

A revolution is currently under way in the structural panel products business with significant changes being made in production of plywood, and the development of the new waferboards, oriented strand boards, and composite panels due primarily to the advent of performance-based standards. These changes bring about the need for significant amounts of research to provide answers for additional uses for the product.

As an extension of the structural panel product analogy, structural lumber substitutes and combinations of panels with these substitutes are being made into components and are seen as a growing business which could reach commodity proportions in the next 5 to 10 years. These products include laminated veneer lumber, composite lumber and parallel strand lumber. As these new products begin to find their way into structural uses, sound research and data base are necessary for their successful implementation and economic utilization.
REFERENCES


