CHAPTER 9

Properties of Composite Panels

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1. INTRODUCTION

The opportunities offered by lignocellulosic composites—such as optimized performance, minimized weight and volume, cost effectiveness, fatigue and chemical resistance, and resistance to biodegradation—are available to virtually every manufacturer. Researchers in the area of materials technology are showing increased interest in the benefits of composite technology. The objective of composite technology is to produce a product with performance characteristics that combine the beneficial aspects of each constituent. New composites are produced with an aim to either reduce the cost of production or to improve performance, or both.

Standards for composite panels are essential for product acceptance in major markets because they give distributors and wood users some assurance that the products possess minimum specific quality levels. Standards which first were recognized for their value as mass production techniques came into common use and the industrial revolution accelerated. At least three standards organizations have a major influence on the quality of composite panels manufactured for most domestic U.S. markets and many foreign markets (Carll, 1982). The American Society for
Testing and Materials (ASTM) and the American National Standards Institute (ANSI) are the organizations currently most active in developing voluntary standards in the United States; ANSI is the U.S. representative regarding standards with the International Standards Organization (ISO).

Each country generally has developed standards for the production and/or use of various panel products. Because of the complexity of this subject on a worldwide basis, we have chosen to discuss the standards and test methods for composite panels produced in the United States.

By way of a brief historical review, it is interesting to note that the first insulating board plant in the United States that used agricultural byproducts, such as bagasse or sugarcane, wheat straw, and corn stalk, was established at Marrero, Louisiana in 1920 (Youngquist et al., 1993). The first hardboard plant was built in the late 1920s. Particleboard was first developed in Germany during World War II and was introduced into the United States in the early 1950s.

This chapter addresses the physical and mechanical properties of composite board products made from wood- and agro-based lignocellulosic materials. To evaluate the performance of various panel products, we first review the classification of the major types of composite panels and then describe the test methods generally used to determine the behavior of these composites. Then, we discuss property requirements of various panel-type composite products. We conclude with a description of properties of composite board made from various types of lignocellulosic-based particles and fibers.

2. EXISTING WOOD COMPOSITE PANELS

2.1 Background Information

Because wood properties vary among species, between trees of the same species, and between pieces from the same tree, wood in the solid form cannot match wood in the comminuted and reconstituted form in providing materials with a wide range of properties that can be controlled in processing. When processing variables are properly selected, the end result can sometimes surpass nature’s best effort. Material science normally deals with the influence of changes on properties at the molecular level. With reconstituted wood materials, the level at which change is produced is the fiber, particle, or flake. Changes in properties are created partially by combining, reorganizing, or stratifying these elements. Although the molecular structure of chemically changing the wood element itself, addition of chemicals to improve the product’s resistance to decay and insect attack, and treatments for fire retardancy may also be made. Application of these treatments is relatively easy when wood is in the comminuted form, before it is converted into the final product configuration, whereas it is quite difficult in solid wood because the treating chemicals do not diffuse easily throughout solid wood.

The basic element for reconstituted wood materials may be the fiber, as it is in paper, but it can also be larger wood particles composed of many fibers and varying
2.2 Definition of Wood-Based Composites

Marra (Marra, 1972) discussed a number of wood elements and developed a nonperiodic table of wood elements (Figure 9.1). These elements range from logs to lumber to thin lumber or thick veneer, and down to paper, fibers, wood flour and cellulose.

This table provides an overall view of the many types of wood components or elements that can be used to produce a wood-based composite product.

Currently, the term *composite* is being used to describe any wood material glued together. This product mix ranges from fiberboards to laminated beams and components. A logical basis (Maloney, 1986) for classifying wood composites has been suggested as follows:

<table>
<thead>
<tr>
<th>The Family of Composite Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Veneer-Based Materials</strong></td>
</tr>
<tr>
<td>- Plywood</td>
</tr>
<tr>
<td>- Laminated Veneer Lumber (LVL)</td>
</tr>
<tr>
<td>- Parallel-Laminated Veneer (PLV)</td>
</tr>
<tr>
<td><strong>Laminates</strong></td>
</tr>
<tr>
<td>- Laminated Beams</td>
</tr>
<tr>
<td>- Overlayed Materials</td>
</tr>
<tr>
<td>- (panels or shaped materials combined with non-wood materials such as metal, plastic, and fiberglass)</td>
</tr>
<tr>
<td><strong>Composite Materials</strong></td>
</tr>
<tr>
<td>- Fiberboard</td>
</tr>
<tr>
<td>- Medium Density Fiberboard (MDF)</td>
</tr>
<tr>
<td>- Particleboard</td>
</tr>
<tr>
<td>- Waferboard</td>
</tr>
<tr>
<td>- Oriented Waferboard (OWB)</td>
</tr>
<tr>
<td>- Oriented Strandboard (OSB)</td>
</tr>
<tr>
<td>- Comply* PLY</td>
</tr>
<tr>
<td><strong>Edge-Glued Material</strong></td>
</tr>
<tr>
<td>- Lumber panels</td>
</tr>
<tr>
<td>- Components</td>
</tr>
<tr>
<td>- I-Beams</td>
</tr>
<tr>
<td>- T-Beam Panels</td>
</tr>
<tr>
<td>- Stress-Skin Panels</td>
</tr>
</tbody>
</table>

1 A registered trademark of APA-Engineered Wood Association, Tacoma, WA.
The above noted composite materials fill a number of non-structural and structural applications in product lines ranging from panels for interior covering purposes to panels for exterior uses to applications in furniture and in support structures in many different types of buildings. This chapter will concentrate on those products that can be made from either wood or other agro-based particle or fiber resources, and which fall into Maloney’s subcategory termed composite materials.

Figure 9.2 provides a useful way to further classify composite materials, presents a very good overview of the types of products that are discussed in this chapter, and provides a quick reference to how these composite materials compare to solid wood and plywood from a density and general processing standpoint.

This shows the raw material classifications of fibers, particles, and veneers on the left-hand y-axis and shows the specific gravity on the x-axis. The right-hand y-axis describes in general terms the processing that takes place to produce a particular product and is classified either as wet or dry processed materials. Note that wet-processed materials are those usually dealt with in fiber form and may include up to 1% adhesive and a small added component of wax. The dry process includes roundwood or wood which is a waste product in a lumber or planing operation. This material is fiberized and dried; adhesive is added in a separate operation, and then the particles are hot-pressed into final configuration. Figure 9.3 provides examples of some of the composite materials that are represented in the schematic format in Figure 9.2.
Figure 9.3 Examples of various composite products.
3. CLASSIFICATION OF COMPOSITE PANELS

The major types of composite panels are generally categorized either by the size of the material from which they are made or by a term that describes the broad end-use of the product. This section describes and explains various composite panels which can easily be produced from various lignocellulosic resources.

3.1 Fiberboard

Lignocellulosic materials are first reduced to fibers or fiber bundles and then put back together by special forms of manufacture into fiberboard panels. Fiberboard is broadly classified into three groups: insulating board, medium density fiberboard, and hardboard. Insulating board is referred to as cellulosic fiber insulating board in ASTM C208 (ASTM, 1994d) and as cellulosic fiberboard in ASTM D1554 (ASTM, 1994e) and ANSI standard ANSI/AHA A194.1 (AHA, 1985). The range of uses and specially developed products within these broad classifications require further division of the products, as shown in Table 9.1.

<table>
<thead>
<tr>
<th>Board type</th>
<th>Density (kg/m³)</th>
<th>Density (lb/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation board</td>
<td>160–500</td>
<td>10–31.2</td>
</tr>
<tr>
<td>Medium density fiberboard</td>
<td>64–800</td>
<td>40–50</td>
</tr>
<tr>
<td>Medium density hardboard</td>
<td>500–800</td>
<td>31.2–50</td>
</tr>
<tr>
<td>Hardboard</td>
<td>500–1,450</td>
<td>31.2–90</td>
</tr>
<tr>
<td>High density hardboard</td>
<td>800–1,280</td>
<td>50–80</td>
</tr>
</tbody>
</table>

3.1.1 Insulating Board

Insulating board is a generic term for a homogeneous panel that is made from interfelted lignocellulosic fibers and that has been consolidated under heat to a density range between 160 and 500 kg/m³. The many different types, names, and uses of these boards are given in Table 9.2.

3.1.2 Medium Density Fiberboard

Medium density fiberboard (MDF) is made from lignocellulosic fibers combined with a synthetic resin. The dry-process technology utilized to manufacture MDF is a combination of that used in the particleboard industry and that used in the hardboard industry. There are three density levels for MDF:

- Low <640 kg/m³
- Medium 640–800 kg/m³
- High >800 kg/m³
3.1.3 Hardboard

Hardboard is a generic term for a homogeneous panel that is made from inter-felted lignocellulosic fibers and has been consolidated under heat and pressure to a density of 500 kg/m³ or more.

3.2 Particleboard

Particleboard panel products typically are made from small lignocellulosic particles and flakes that are bonded together with a synthetic adhesive under heat and pressure. The density levels for particleboard are the same as those for MDF.

3.3 Mineral-Bonded Panels

In mineral-bonded panels, lignocellulosic fibers are mixed with inorganic binders like magnesium oxysulphate, magnesite gypsum, or Portland cement. The panels range in density from 290-1,250 kg/m³. Agro-fibers can be blended with cement, formed into mats, and pressed to a density of 460–640 kg/m³ to form a panel product.

**Table 9.2 Types, Grades, and Intended Uses for Cellulosic Fiber Insulating Board**

<table>
<thead>
<tr>
<th>Types</th>
<th>Grades</th>
<th>Name</th>
<th>Intended Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>—</td>
<td>Sound-deadening board</td>
<td>In wall assemblies to control sound transmission</td>
</tr>
<tr>
<td>II</td>
<td>—</td>
<td>Roof insulating board</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Roof insulating board</td>
<td>Under built-up roof systems</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Roof insulating board</td>
<td>Under single-ply roof systems</td>
</tr>
<tr>
<td>III</td>
<td>—</td>
<td>Ceiling tiles and panels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Non-acoustical uses</td>
<td>Decorative wall and ceiling coverings</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Acoustical uses</td>
<td>Decorative sound-absorbing wall and ceiling coverings</td>
</tr>
<tr>
<td>IV</td>
<td>—</td>
<td>Wall sheathing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Regular</td>
<td>Wall sheathing in frame construction</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Structural</td>
<td>Wall sheathing in frame construction for exterior wall bracing</td>
</tr>
<tr>
<td>V</td>
<td>—</td>
<td>Backer board</td>
<td>Behind exterior finish in wall assemblies—no structural requirement</td>
</tr>
<tr>
<td>VI</td>
<td>—</td>
<td>Roof deck</td>
<td>Roof decking for flat, pitched, or shed-type, open-beamed, ceiling-roof construction</td>
</tr>
</tbody>
</table>


**STANDARDS AND TEST METHODS FOR COMPOSITE PANELS**

Standards for composite panel products are voluntary in the United States. However, certification of conformance with a standard is advantageous to a product manufacturer from the standpoint of marketing and product conformance. Standards
also permit ready identification of product quality and suitability and protect pro-
ducers and distributors from cost-cutting competitors. Because the construction
market in the United States is so important for composite panel producers, building
code approval is a significant marketing consideration: reference to a standard in
the building code requires the use of products manufactured under that standard. In
addition, building codes usually demand conformance of composite panel products
to a specific standard. Commodity standards, frequently referred to as product
standards, can be classified further as manufacturing method standards or laboratory
test standards. Panel performance is generally evaluated using dimensional tests,
physical property tests, and mechanical property tests.

4.1 Dimensional Tests

Methods of measuring panel dimensional properties and the required accuracy
of these measurements for composite panel products are defined in ASTM D1037.
Tolerance limits for size, thickness, squareness, and straightness are listed in the
standards discussed in Section 4.2 on property requirements of composite panels.

4.2 Physical Property Tests

The physical property tests discussed in this section refer to American Society
for Testing and Materials (ASTM) standard D1037 (ASTM, 1994a) unless otherwise
noted.

4.2.1 Moisture Content

The average moisture content of a panel at the time of shipment from the
manufacturer cannot exceed 10% (based on the ovendry weight) for all grades of
particleboard. In the United States, the average moisture content of hardboard should
not be less than 2% nor more than 9%. Three specimens should be cut from different
locations in the panel and the test results averaged. Generally, a 76 mm wide by
152 mm long specimen of full thickness is used to obtain the dimensions to an
accuracy not less than ±0.3% and the weight to an accuracy of not less than ±0.21%.
The ovendry weight of the sample is then obtained after drying the sample at 103
±2°C until constant weight is reached.

Moisture content is calculated as follows:

\[ M = \frac{100 [(w - f)/f]}{f} \]

\( M = \) moisture content (%)
\( w = \) initial weight
\( f = \) final weight when ovendry

4.2.2 Density

Density is an important indicator of a composite’s performance. It virtually
affects all properties of the material. The density of the specimen is determined
using the full thickness of the composite. The dimensions are measured to an accuracy of not less than 0.3%, and the weight is measured to an accuracy of not less than ±0.2%. The density of wood-based composites is generally based on the oven-dry weight, which is obtained after drying a specimen at 103±2°C until constant weight is reached. The density is calculated as follows:

\[
\text{Density (kg/m}^3\text{)} = \frac{f}{Lwt}
\]

\[f = \text{oven-dry weight (kg)}\]
\[L = \text{length of sample (m)}\]
\[w = \text{width of sample (m)}\]
\[t = \text{thickness of sample (m)}\]

Some industries use specific gravity instead of density when referring to a panel product. Specific gravity is the ratio of the density of a material compared to the density of water.

4.2.3 Water Soak Test

The 24 h water soak test determines the water absorption behavior of the composite and the effects of the absorbed water on composite dimensions. The test specimen is 304 by 304 mm or 152 by 152 mm, with edges smoothly and squarely trimmed. The specimen is conditioned to a constant weight and moisture content in a conditioning chamber maintained at a relative humidity (RH) of 65 ± 1% and a temperature of 20 ± 3°C. The specimen is weighed to an accuracy of not less than ±0.2% and the width, length, and thickness are measured to an accuracy of not less than ±0.3%. The thickness is measured at four points midway along each side 25 mm. After 24 h of submersion in distilled water at 20 ± 1°C, the specimen is weighed after the excess water drains off. The thickness is measured at the same four points and the average is obtained. The following calculations can then be made:

(a) **Thickness swelling (%)** = \(\frac{(T_w - T_i)}{T_i} \times 100\)

\[T_w = \text{wet thickness}\]
\[T_i = \text{initial thickness}\]

(b) **Water absorption (%)** = \(\frac{(W_w - W_i)}{W_i} \times 100\)

\[W_w = \text{wet weight}\]
\[W_i = \text{initial weight}\]

Thickness swelling is critical where the composite board is exposed to water or moisture for extended periods.
### 4.2.4 Linear Expansion

The linear expansion test measures the dimensional stability of a composite to changes in moisture content (Figure 9.4). The specimen is generally 76 mm wide and 304 mm long; it needs to be at least 152 mm long. The specimen is first conditioned at RH of 50 ± 2% and a temperature of 20 ± 3°C. The length of each specimen is then measured to the nearest 0.02 mm.

The specimen is then conditioned at a RH of 90 ± 5% and a temperature of 20 ±3°C. Linear expansion is then calculated as follows:

\[
\text{Linear expansion (\%)} = \left( \frac{L_{90} - L_{50}}{L_{50}} \right) \times 100
\]

\(L_{90}\) = length at 90% RH  
\(L_{50}\) = length at 50% RH

Thickness swelling and water absorption can also be calculated at these different conditions of relative humidity.

![Dial gauge comparator for determining linear variation with change in moisture content.](image)

Figure 9.4 Dial gauge comparator for determining linear variation with change in moisture content.

### 4.2.5 Thermal Insulation

Thermal insulation (thermal conductivity) is an important property that relates to heat flow through a composite board. The standard test method is entitled *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate apparatus*, and it is described in the ASTM C177-92 specification (ASTM, 1994b). Specimens approximately 25 mm thick are placed on each side of a hot plate, and the thermal conductivity is measured. Conducting this test is complex because thermal conductivity depends upon environmental and apparatus test conditions, as well as the formulation and density of the composite product.
4.3 Mechanical Property Tests

The mechanical property tests discussed in this section refer to ASTM D 1037 standards (ASTM, 1994a) unless otherwise noted. The mechanical properties of composite boards depend on the moisture content at the time of test. Material tested dry is conditioned to a constant weight and moisture content in a climate chamber maintained at 20° ± 3°C and an RH of 65 ± 1%. There are also several tests for measuring the properties of a composite product at various moisture contents and humidity levels. Material tested wet is soaked in 20° ± 3°C water for 24 h prior to mechanical property testing.

One method of obtaining a measure of the inherent ability of a material to withstand severe exposure conditions is to use an accelerated aging test. Using this method, each sample is subjected to six complete cycles of aging:

- Immerse specimen in water at 49 ± 2°C for 1 h
- Spray specimen with steam and water vapor at 93 ± 3°C for 3 h
- Store at –12 ± 3°C for 20 h
- Heat at 99 ± 2°C in dry air for 3 h
- Spray again with steam and water vapor at 93 ± 3°C for 3 h
- Heat in dry air at 99 ± 2°C for 18 h
- After six cycles, further condition the material at 20 ± 3°C and RH 65 ± 1% for at least 48 h before the test.

A test commonly used in Canada and Europe involves submerging the specimen in boiling water at 100°C for 2 h before property testing (CSA, 1978). The following section describes tests for static bending, tensile strength, dent and impact resistance, and fastener holding strength. Regardless of the moisture content of the specimen at the time of test, the following procedures are commonly used to determine the mechanical properties of composite products.

4.3.1 Static Bending

Static bending tests determine the modulus of rupture and modulus of elasticity of composites (Figure 9.5).

4.3.1.1 Modulus of Rupture

Modulus of rupture (MOR) has become a common measurement of composite board bending strength. The MOR is the ultimate bending stress of a material in flexure or bending, and it is frequently used in comparing one material to another.

\[ \text{MOR} = \frac{3PL}{2bd^2} \]

- \( \text{MOR} \) = modulus of rupture (for midspan loading), kPa
- \( P \) = maximum bending load, N
- \( L \) = length of span, mm, 24× the depth
4.3.1.2 Modulus of Elasticity

Modulus of elasticity (MOE) tests the specimen's ability to resist bending. This property is determined from the slope of the straight-line portion of the load-deflection curve ($P/Y$). The MOE is then calculated by the following formula:

\[
\frac{b}{d} = \text{width of specimen, mm} \quad \text{d} = \text{thickness (depth) of specimen, mm}
\]

\[
\text{MOE} = \frac{P}{Y} \cdot \frac{b}{d}
\]
4.3.2 Tensile Strength

Tensile strength is measured perpendicular (internal bond strength) and parallel to the face of the specimen.

4.3.2.1 Perpendicular to Face

Tensile strength perpendicular-to-face is a measure of the resistance of a material to be pulled apart in the direction perpendicular to its surface. A 50 mm square specimen is bonded with an adhesive to steel or aluminum alloy loading blocks of the same dimensions. The internal bond strength is an important property of composite boards; it is calculated as follows:

\[ IB = \frac{P}{bL} \]

Where:
- \( IB \) = internal bond, kPa
- \( P \) = maximum load, N
- \( b \) = width of specimen, mm
- \( L \) = length of specimen, mm

4.3.2.2 Parallel to Face

Tensile strength in the parallel-to-face orientation (Figure 9.6) is the resistance of a board material to be pulled apart parallel to its surface. The maximum load at the time of fracture is divided by the cross-sectional area (width \( \times \) thickness) of the specimen to give maximum strength.

4.3.3 Dent and impact Resistance

Two tests—face hardness and falling ball impact resistance—are used to measure the resistance of boards to indentation or to the damage that occurs in service when boards are struck by moving objects.

4.3.3.7 Face Hardness

The face hardness (dent resistance) of a composite board specimen is determined by the modified Janka ball test, which records the load required to imbed a steel
“ball” 11.28 mm in diameter to a depth of one half its diameter. The value obtained using this technique is referred to as the hardness value for the specimen.

4.3.3.2 Falling Ball Impact Resistance

The specimen for the impact resistance test is 304 × 304 mm or 152 × 152 mm, with all four edges smoothly and squarely trimmed. The impact strength is the resistance to fracture when a sudden localized load is applied against the face of a panel held between supports. This value is usually obtained by dropping a 50 mm diameter steel ball from increasing heights at the center of the board until the
specimen fails. The height of drop, in millimeters (inches), that produces visible failure on the opposite face of the board is recorded as the index of resistance to impact.

4.3.4 Fastener Holding Strength

The procedures for testing fastener holding strength follow basic ASTM D1037 standards (ASTM, 1994a) as well as individual standards: ANSI A208.1-1993 Particleboard (National Particleboard Association, 1993), ANSI A208.2-1994 Medium Density Fiberboard (National Particleboard Association, 1994), and ANSI/AHA A135.6-1989 Hardboard Siding (AHA, 1989). Fastener resistance is an important property of composite panels used in structural applications such as sheathing. The tests discussed in this section are related to the capability of a composite material to be fastened with either screws or nails.

4.3.4.1 Face Screw Holding

This test measures the withdrawal resistance of screws from the face of the board. The specimen for this test is at least 76 mm wide by 102 mm long. Number 10 Type AB 25 mm sheet-metal screws are threaded into the specimen to a depth of 17 mm. Lead holes are predrilled using a bit 3.2 mm in diameter. If the boards are less than 19 mm thick, the specimen is made from two thicknesses of a sample product, which are laminated together with an adhesive. The screw is withdrawn immediately after it has been imbedded.

4.3.4.2 Edge Screw Holding

This test measures the withdrawal resistance of screws from the edge of the board. The size of the test specimen is the same as that noted for the face screw holding test. The same type of sheet metal screw is threaded into the edge of the board at the mid-thickness 17 mm. A lead hole, the same size as that for the face screw holding test, is predrilled. Boards less than 16 mm thick are not tested. The screw is withdrawn immediately after it has been imbedded.

4.3.4.3 Direct Nail Withdrawal

This test is made using nails that are driven through the specimen from face-to-face to measure the resistance to withdrawal, in a plane normal to the face (Figure 9.7). The specimen is at least 76 mm wide and 152 mm long. Nails 2.8 mm in diameter are used, and the withdrawal tests are made immediately after the nails have been driven into the specimen.

4.3.4.4 Nail-head Pull-through

This test measures the resistance of a composite product to pulling the head of a nail or other fastener through the board. It is designed to simulate the conditions
encountered with forces that tend to pull paneling or sheathing from a wall or siding. The specimen is 76 mm wide by 152 mm long. A common wire nail, 2.8 mm in diameter, is driven through the board specimen at a right angle to the face, with the nail head flush with the surface of the board.

### 4.3.4.5 Lateral Nail Resistance

This test is made to measure the resistance of a nail to the lateral movement through a composite board (Figure 9.8). The specimen is 76 mm wide and can be any length. A nail 2.8 mm in diameter is driven at a right angle into the face of the panel, with the nail centered on the width. For hardboard siding, a 3.3 mm diameter nail is used, spaced 9.5 mm from the edge of the specimen.

### 4.4 Chemical Tests

There are many chemical tests for measuring various properties of composite panels, such as procedures for determining acidity and the amount of extractives. Many of the more recently established chemical tests relate to monitoring and controlling air or water quality during the manufacture of composite products.
Two important chemical properties related to composite panels include formaldehyde content and ash content. Tests for determining these properties are described in the following text.

4.4.1 Formaldehyde

Formaldehyde emissions are generally determined for composite panels bonded with urea formaldehyde. The test method is described in ASTM E1333-90—Standard Test Method for Determining Formaldehyde Levels From Wood Products Under Defined Test Conditions Using a Large Chamber (ASTM, 1991). This test method
measures the formaldehyde level from wood products under conditions designed to simulate product use in structures such as manufactured homes.

The material is generally tested within 30 days and is sealed before conditioning. Specimens are conditioned on edge with a minimum distance of 153 mm between each panel for 7 days at 24°C and 50% RH. Specimens are then inserted into the test chamber at these same conditions for a minimum of 16 h but no more than 20 h, at which time the chamber air is sampled and analyzed for formaldehyde concentration. The formaldehyde concentration in the air is set by standards for different products and is dependent on application of those products. Chamber test concentrations are useful in comparing the formaldehyde emission performance of products.

### 4.4.2 Ash Content

The test for ash content covers the determination of ash in wood or wood products. The test method is described in ASTM D1102-84—Standard Test Method for Ash in Wood (ASTM, 1994c). The method requires a crucible, a muffle furnace, an analytical balance, and a drying oven. Ash content is expressed as percentage of the residue after dry oxidation at 580°C to 600°C of the total ovendry lignocellulosic materials. The test specimen consists of 2 g of wood, ground to pass through a No. 40 sieve. The empty and covered crucible is ignited over a burner or in the muffle furnace at 600°C. The crucible is then cooled in a desiccator and weighed to the nearest 0.1 mg. Then, 2 g of the specimen is placed in the crucible. The uncovered crucible and the specimen are then weighed and dried in an oven at 100–105°C. After 1 h, the cover is replaced on the crucible. The specimen is then weighed after cooling. This drying operation is repeated until the weight is constant to 0.1 mg. After the weight of the ovendry specimen is recorded, the crucible and contents are placed in a muffle furnace and ignited until all the carbon is eliminated. The crucible is then heated slowly to avoid flaming and loss of the specimen. The final ignition temperature is 580–600°C. The specimen is accurately weighed after cooling. The ash content is calculated as follows:

\[
\text{Ash content (\%)} = \left( \frac{W_1}{W_2} \right) \times 100
\]

\[W_1 = \text{weight of ash}\]
\[W_2 = \text{weight of ovendry sample}\]

### 5. PROPERTY REQUIREMENTS OF COMPOSITE PANELS

A number of properties could be considered critical to the performance of a specific wood-based composite product, depending upon its end use. Important in some respects to all composites are dimensional stability, strength and stiffness, and fastener-holding properties.

The properties of most composite board products are determined according to ASTM standard (ASTM, 1994a), and to a considerable extent, these properties either
suggest or limit the uses. In the following text, fiberboard and particleboard are grouped into various categories suggested by manufacturing process, properties, and use. In general, these products are ones that can easily be made from either wood or other agro-based fibrous materials.

5.1 Fiberboard

Fiberboard includes insulating board, medium density fiberboard, and hardboard.

5.1.1 Fiber Insulating Board

Table 9.3 shows requirements for some physical and mechanical properties of insulating board, published in ASTM C208-9—Standard Specification for Cellulosic Fiber Insulating Board (ASTM, 1994d). Physical properties are also included in the ANSI Standard for Cellulosic Fiberboard, ANSI/AHA 194.1 (AHA, 1985). These products are used for such applications as sound deadening, sheathing, shingle backing, and insulation.

5.1.2 Medium Density Fiberboard

Minimum property requirements, as specified by the American National Standard for MDF (ANSI A208-1994) (National Particleboard Association, 1994), are given in Table 9.4. The furniture industry is by far the dominant MDF market. Medium density fiberboard is frequently used in place of solid wood, plywood, and particleboard in many furniture applications. It is also used for doors, moldings, and trim components.

5.1.3 Hardboard

Property requirements for hardboard are presented in Table 9.5 which classifies hardboard by surface finish, thickness, and minimum physical and mechanical properties, for three classifications, as specified by the American National Standard for Basic Hardboard (ANSI/AHA A135.4-1995) (AHA, 1995). The uses for hardboard generally can be subdivided according to uses developed for construction, furniture and furnishings, cabinet and store work, appliances, and automotive and rolling stock. Typical hardboard products are prefinished paneling, house siding, floor underpayment, and concrete form board.

5.2 Particleboard

Tables 9.6 and 9.7 show requirements for grades of particleboard and particleboard flooring products, as specified by the American National Standard for Particleboard (ANSI A208. 1-1993) (National Particleboard Association, 1993). Today, approximately 85% of interior-type particleboards are used as core stock for a wide variety of furniture and cabinet applications. Floor underpayment and manufactured
<table>
<thead>
<tr>
<th>Physical requirements</th>
<th>Sound-deadening board</th>
<th>Roof insulation board</th>
<th>Ceiling tiles and panels (Grades 1 &amp; 2)</th>
<th>Wall sheathing</th>
<th>Becker board</th>
<th>Roof deck</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 mm</td>
<td>11 mm</td>
<td>13 mm</td>
<td>11 mm</td>
<td>13 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>Thermal conductivity (k) (max), W/m·K at 24 ± 3°C</td>
<td>0.055</td>
<td>0.055</td>
<td>0.055</td>
<td>0.055</td>
<td>0.055</td>
<td>0.058</td>
</tr>
<tr>
<td>Transverse strength (either direction) (min), N</td>
<td>53.4</td>
<td>31.1</td>
<td>51.1</td>
<td>62.3</td>
<td>124.6</td>
<td>62.3</td>
</tr>
<tr>
<td>Tensile strength parallel to surface (min), kPa</td>
<td>1,034</td>
<td>345</td>
<td>345</td>
<td>345</td>
<td>1,034</td>
<td>1,034</td>
</tr>
<tr>
<td>Tensile strength perpendicular to surface (min), kPa</td>
<td>28.7</td>
<td>23.9</td>
<td>23.9</td>
<td>23.9</td>
<td>28.7</td>
<td>28.7</td>
</tr>
<tr>
<td>Water absorption by volume (max), %</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Linear expansion, 50–90% RH (max), %</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Flame spread index, finish surface (max)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Vapor permeance, pressure differential, mg/s·m²·kPa</td>
<td>0.287</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Modulus of rupture (min), kPa</td>
<td>1,655</td>
<td>9,685</td>
<td>965</td>
<td>552</td>
<td>276</td>
<td>1,896</td>
</tr>
<tr>
<td>Deflection at specified min load (max), mm</td>
<td>22</td>
<td>32</td>
<td>16</td>
<td>8</td>
<td>19</td>
<td>11</td>
</tr>
</tbody>
</table>
### Table 9.3 Physical Property Requirements for Cellulosic Fiber Insulating Board

<table>
<thead>
<tr>
<th>Physical requirements</th>
<th>Roof Insulation board (Grade 1)</th>
<th>Grade 2 (Grades 1 &amp; 2)</th>
<th>Ceiling tiles and panels</th>
<th>Wall sheathing</th>
<th>Backer board</th>
<th>Roof deck</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 mm</td>
<td>11 mm</td>
<td>13 mm</td>
<td>13 mm</td>
<td>14 mm</td>
<td>9 mm</td>
</tr>
<tr>
<td></td>
<td>11 mm</td>
<td>13 mm</td>
<td>25 mm</td>
<td>16 mm</td>
<td>13 mm</td>
<td>9 mm</td>
</tr>
<tr>
<td></td>
<td>13 mm</td>
<td>51 mm</td>
<td>25 mm</td>
<td>13 mm</td>
<td>13 mm</td>
<td>76 mm</td>
</tr>
<tr>
<td></td>
<td>51 mm</td>
<td>51 mm</td>
<td>51 mm</td>
<td>13 mm</td>
<td>20 mm</td>
<td></td>
</tr>
<tr>
<td>Modulus of elasticity (min), MPa</td>
<td>278</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deflection span ratio</td>
<td>1/240</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture content by weight (max), %</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

* Board dimension is thickness.

* Physical properties listed in this column, except flame spread index, apply to the base material before punching, drilling, perforating, or embossing.

* The B-8 transverse load and modulus of rupture (MOR) requirements are not required for wall sheathing applications where the manufacturer certifies that the product will meet the specified racking requirements when run in accordance with Methods E 72, in conjunction with Appendix D of the IID Minimum Property Standards, 490C.1 REV-1. In addition, the product is applied vertically and fastened 152 mm apart to intermediate framing and 76 mm apart around the edges of the sheets. Racking strengths of 23.2 kN dry and 17.8 kN wet are required. As an alternative, building code requirements may be specified.

* Tensile strength requirements shall be applicable only on thicknesses up to and including 25 mm.

* Water absorption for 13 mm structural wall sheathing is determined by the 24-h test in accordance with Test Methods D 1037 using 15% as the maximum. Water absorption for all other products is determined by the 2-h test in accordance with Test Methods C 209.

* For roof deck products with a vapor retarder, the maximum should be 0.029. For roof deck products without a vapor retarder, there is no requirement for permeance.

* For roof decking, MOR is determined using Methods D 2164. Matched samples are to be tested before and after accelerated aging. Minimum MOR for unaged samples shall be 155 kPa. For aged samples, the minimum shall be no less than 50% of the unaged test result.

* Using Methods D 2164.

PROPERTIES OF COMPOSITE PANELS

Low-density panels produced in a thickness of 38 mm are used for solid core doors.

6. COMPOSITE PANELS FROM AGRO-BASED FIBERS

Composite panels made from agricultural materials are in the same product category as wood-based composite panels and include low-density insulating board, medium-density fiberboard, hardboard, and particleboard. Composite panel binders may be synthetic thermosetting resins or modified naturally-occurring resins like tannin or lignin, starches, thermoplastics, and inorganics. There seems to be little restriction of what has been tried and what may work.

The following section describes some properties of composite panels made from particles and fibers of bagasse, bamboo, banana stem, coconut and coir, coffee husk, flax, kenaf, reed, rubber tree, rice husk, and miscellaneous fibers. The data were

<table>
<thead>
<tr>
<th>Table 9.4 Medium Density Fiberboard (MDF) Property Requirementsa,b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product class</strong></td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td><strong>Interior MDF</strong></td>
</tr>
<tr>
<td>HD</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>MD</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Exterior MDF</strong></td>
</tr>
<tr>
<td>MD–Exterior glue</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>


b Metric property values shall be the primary values used in determining product performance requirements.

c MOR = modulus of rupture.
d MOE = modulus of elasticity.
e HD = density greater than 600 kg/m³, MD = density between 640–600 kg/m³ (40–50 lb/ft³), LD = density less than 640 kg/m³.
f Maximum emission when tested in accordance with ASTM E 1333–1990, Standard test method for determining formaldehyde levels from wood products under defined test conditions using a large chamber (ASTM, 1991).


obtained from references cited in a literature review conducted by the Forest Products Laboratory and the Department of Forestry at the University of Illinois, Urbana-Champaign (Youngquist et al., 1994).

The research studies included in this review focused on the use of nonwood plant fibers for building materials and panels. The studies covered (1) methods for efficiently producing building materials and panels from nonwood plant fibers; (2) treatment of fibers prior to board production; (3) process variables, such as press time and temperature, press pressure, and type of equipment; (4) mechanical and physical properties of products made from nonwood plant materials; (5) methods used to store nonwood plant materials; (6) use of nonwood plant fibers as stiffening agents in cementitious materials and as refractory fillers; and (7) cost-effectiveness of using nonwood plant materials. More than 30% of the studies addressed the use of bagasse and rice as raw materials in building elements. Other materials widely studied included bamboo (10% of studies), coconut and coir (7%), flax (6%), and straw (6%).

Virtually all studies failed to examine the durability of the product. Of the few studies that did investigate durability, most focused on cement and concrete rooting panels and sheets. This literature review indicates that additional research is needed to obtain information on long-term durability and the influence of weathering on the performance of materials. Moreover, future research needs to focus on comparing the product against product standards, such as American Standard for Testing and

<table>
<thead>
<tr>
<th>Class</th>
<th>Normal thickness (mm)</th>
<th>Water absorption based on weight (%)</th>
<th>Thick. swelling (%)</th>
<th>MOR (min avg/panel)</th>
<th>Parallel to surface MPa</th>
<th>Perpendicular to surface MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempered</td>
<td>2.1</td>
<td>30</td>
<td>25</td>
<td>41.4</td>
<td>20.7</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>25</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>25</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>25</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>15</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>2.1</td>
<td>40</td>
<td>30</td>
<td>31</td>
<td>15.2</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>35</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>35</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>35</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>25</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.9</td>
<td>20</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service-tempered</td>
<td>3.2</td>
<td>35</td>
<td>30</td>
<td>31</td>
<td>3.8</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>30</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>20</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 9.6 Requirements for Grades of Particleboard

<table>
<thead>
<tr>
<th>Grade&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MOR MPa</th>
<th>MOE MPa</th>
<th>Internal bond MPa</th>
<th>Hardness N</th>
<th>Linear expansion max avg (%)</th>
<th>Screw-holding Face N</th>
<th>Edge N</th>
<th>Formaldehyde maximum emission (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-1</td>
<td>16.5</td>
<td>2,400</td>
<td>0.9</td>
<td>2,225</td>
<td>NS&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1,800</td>
<td>1.325</td>
<td>0.3</td>
</tr>
<tr>
<td>H-2</td>
<td>20.5</td>
<td>2,400</td>
<td>0.9</td>
<td>4,450</td>
<td>NS</td>
<td>1,900</td>
<td>1.550</td>
<td>0.3</td>
</tr>
<tr>
<td>H-3</td>
<td>23.5</td>
<td>2,750</td>
<td>1</td>
<td>6,675</td>
<td>NS</td>
<td>2,000</td>
<td>1.550</td>
<td>0.3</td>
</tr>
<tr>
<td>M-1</td>
<td>11</td>
<td>1,725</td>
<td>0.4</td>
<td>2,225</td>
<td>0.35</td>
<td>NS</td>
<td>NS</td>
<td>0.3</td>
</tr>
<tr>
<td>M-S*</td>
<td>12.5</td>
<td>1,900</td>
<td>0.4</td>
<td>2,225</td>
<td>0.35</td>
<td>900</td>
<td>800</td>
<td>0.3</td>
</tr>
<tr>
<td>M-2</td>
<td>14.5</td>
<td>2,250</td>
<td>0.45</td>
<td>2,225</td>
<td>0.35</td>
<td>1,000</td>
<td>900</td>
<td>0.3</td>
</tr>
<tr>
<td>M-3</td>
<td>16.5</td>
<td>2,750</td>
<td>0.55</td>
<td>2,225</td>
<td>0.35</td>
<td>1,100</td>
<td>1,000</td>
<td>0.3</td>
</tr>
<tr>
<td>LD-1</td>
<td>3</td>
<td>550</td>
<td>0.1</td>
<td>NS</td>
<td>0.35</td>
<td>400</td>
<td>NS</td>
<td>0.3</td>
</tr>
<tr>
<td>LD-2</td>
<td>5</td>
<td>1,025</td>
<td>0.15</td>
<td>NS</td>
<td>0.35</td>
<td>550</td>
<td>NS</td>
<td>0.3</td>
</tr>
</tbody>
</table>

<sup>a</sup> Particleboard made with phenol–formaldehyde-based resins do not emit significant quantities of formaldehyde. Therefore, such products and other particleboard products made with resin not containing formaldehyde are not subject to formaldehyde emission conformance testing. Source: ANSI A208.1–1993 (National Particleboard Association, 1993), National Particleboard Association, Particleboard, ANSI A 208.1–1993, American National Standards Institute, Gaithersburg, MD, 1993.

<sup>b</sup> Panels designated as “exterior glue” must maintain 50% MOR after ASTM D 1037 accelerated aging.

<sup>c</sup> H = density greater than 800 kg/m³, M = density between 640–800 kg/m³, LD = density less than 640 kg/m³.

<sup>d</sup> NS = Not specified.

* Grade M-S refers to medium density, “special” grade. This grade was added to the Standard after grades M-1, M-2, and M-3 had been established. Grade M-S falls between M-1 and M-2 in physical properties.

### Table 9.7 Requirements for Grades of Particleboard Flooring Products

<table>
<thead>
<tr>
<th>Grade&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MOR MPa</th>
<th>MOE MPa</th>
<th>Internal bond MPa</th>
<th>Hardness N</th>
<th>Linear expansion max avg (%)</th>
<th>Formaldehyde max emission (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBU</td>
<td>11</td>
<td>1,725</td>
<td>0.4</td>
<td>2,225</td>
<td>0.35</td>
<td>0.2</td>
</tr>
<tr>
<td>D-2</td>
<td>16.5</td>
<td>2,750</td>
<td>0.55</td>
<td>2,225</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>D-3</td>
<td>19.5</td>
<td>3,100</td>
<td>0.55</td>
<td>2,225</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

<sup>a</sup> Particleboard made with phenol–formaldehyde-based resins do not emit significant quantities of formaldehyde. Therefore, such products and other particleboard products made with resin not containing formaldehyde are not subject to formaldehyde emission conformance testing. Source: ANSI A208.1–1993 (National Particleboard Association, 1993), National Particleboard Association, Particleboard, ANSI A 208.1–1993, American National Standards Institute, Gaithersburg, MD, 1993.

<sup>b</sup> Grades listed in this table shall also comply with the appropriate requirements listed in Section 3. Panels designated as “exterior glue” must maintain 50% MOR after ASTM D–1037 accelerated aging (Paragraph 3.3.3).

<sup>c</sup> PBU = underlayment; D = Manufactured Home Decking.

The properties reported here are from different research studies from various parts of the world. The references are cited at the bottom of the tables; the data are limited to those appearing in the reports cited in Youngquist et al. (1994) and necessarily differ from fiber to fiber. No attempt was made to determine the test methods used to obtain these data.

6.1 Bagasse/Guar/Sugarcane

Properties of selected composite boards made from bagasse, guar, and sugarcane are shown in Table 9.8.

Table 9.8 Properties of Selected Composite Boards Made from Bagasse, Guar, and Sugarcane

<table>
<thead>
<tr>
<th>Material</th>
<th>Type of board</th>
<th>Thickness (mm)</th>
<th>Density (kg/m²)</th>
<th>MOE (MPa)</th>
<th>MOR (MPa)</th>
<th>Water absorption (24 h) (%)</th>
<th>Thickness swell (24 h) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse, guar, sugarcane</td>
<td>Particle board</td>
<td>12–20</td>
<td>520–630</td>
<td>1,400–2,000</td>
<td>16.7–25.5</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Fiberboard</td>
<td>6–35</td>
<td>300–750</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Fiberboard</td>
<td>4.3</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Bagasse, corn, sunflower, flax</td>
<td>Particle board</td>
<td>—</td>
<td>720</td>
<td>3,800</td>
<td>16.3</td>
<td>58.5</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>Fiberboard</td>
<td>—</td>
<td>810–850</td>
<td>22.6–26.5</td>
<td>14–15</td>
<td>8–10</td>
<td>—</td>
</tr>
<tr>
<td>Bagasse + CaSO₄ + 5H₂O</td>
<td>Plasterboard</td>
<td>—</td>
<td>560</td>
<td>2.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(cement)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>Bagasse + asphalt</td>
<td>Composite board</td>
<td>—</td>
<td>900–1,000</td>
<td>19.6–24.5</td>
<td>&lt;10</td>
<td>5</td>
<td>—</td>
</tr>
</tbody>
</table>

*MOE is modulus of elasticity; MOR, modulus of rupture.


Some properties of bagasse composite panels are shown in Figure 9.9. Specifications for these panels are 92% bagasse, 8% urea–formaldehyde, 0.74 specific gravity, and 7.6 mm thickness (Salyer and Usmani, 1982).

6.2 Bamboo

Properties of several types of boards made from bamboo are shown in Table 9.9.

6.3 Banana

Particleboards have been made using banana stalk and wood chips (Youngquist et al., 1994). Urea-formaldehyde resin (10%) was used as a binder and boards with
a density of 590–720 kg/m³ were prepared (Pablo et al., 1975). The strength of the boards increased as the proportion of wood chips increased in the mixture.

### 6.4 Coconut/Coir

Properties of boards made from coconut or coir (dust, husk, shell, or shell flour) are seen in Table 9.10.

### 6.5 Coffee Bean

Composite boards made from coffee bean hull and grounds have been reported (Youngquist et al., 1994); however, no strength data was given. The boards were
made using varying amounts of urea-formaldehyde resin, to a thickness of 127 mm and a density of 1,100 kg/m³. Increased resin content resulted in improved board strength and water resistance (Tropical Products Institute, 1963).

### 6.6 Cotton

Pandey et al. (1979) reported the following properties for particleboard made from cotton (seed hull/husk, stalk):

<table>
<thead>
<tr>
<th>Density</th>
<th>710 kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOR</td>
<td>6.6 MPa</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>2.9 MPa</td>
</tr>
<tr>
<td>Water absorption (2 h)</td>
<td>38%</td>
</tr>
</tbody>
</table>

Cotton stalk composites have been studied as a substitute for lumber (Zur Burg, 1943).

Some properties of composition panels made from undebarked cotton stalks are shown in Figure 9.10. Specifications for these composition panels are 97% refined undebarked cotton stalk, 3% phenolic resin, 0.82 specific gravity, and 2.8 mm thickness. Thickness swell and water absorption time values are unknown (Fadl et al., 1978).

### 6.7 Flax, Linseed

Properties of particleboard made from flax and/or linseed shives or straw are shown in Table 9.11.
Narayanamurti and Singh (1963) reported the following properties for particleboard made from grasses:

Density \( \quad 565-741 \text{ kg/m}^3 \)

Tensile strength \( \quad 7.2-9.8 \text{ MPa} \)

Bagby and Clark (1976) reported the following properties for hardboard made from kenaf

<table>
<thead>
<tr>
<th>Material</th>
<th>Ref.</th>
<th>Type of board</th>
<th>Density (kg/m³)</th>
<th>MOR (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Compression strength (MPa)</th>
<th>Water absorption (2 h) (%)</th>
<th>Thickness swell (2 h) (%)</th>
<th>Heat conductivity (Kcal/m²h/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flax, linseed</td>
<td>1</td>
<td>Particle-board</td>
<td>600–650</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Fiberboard</td>
<td>180–220</td>
<td>0.59–1</td>
<td>0.7</td>
<td>20</td>
<td>6.2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Insulating board</td>
<td>790</td>
<td>.2</td>
<td>5.7</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.047</td>
</tr>
<tr>
<td>Flax + abroite</td>
<td>4</td>
<td>Plaster-board, cement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( ^* \) MOR is modulus of rupture.

Some properties for kenaf composition panels are shown in Figure 9.11. Specifications for these panels are 92% depithed kenaf bast fiber, 7% urea-formaldehyde, 1% wax, 0.74 specific gravity, and 12.7 mm thickness. Thickness swell and water absorption values reflect 2 h of immersion (Chow, 1974).


6.10 Poppy

Chawla (1978) reported a density of 1000 kg/m³ for fiberboard made from poppy straw.

6.11 Reed

Al-Sudani et al. (1988) reported thickness of 16 mm and density of 640 kg/m³ for particleboard made from reed stalks.

6.12 Rice

Properties of boards made from rice husks are shown in Table 9.12. Rice husks or their ash are used in cement block and other cement products. The addition of the hulls increases thermal and acoustic properties (Govindarao, 1980). Some properties of selected rice husk composition panels are presented in Figure 9.12. Specifications for these composition panels are 0.94 specific gravity and 5.1 mm thickness. Husk and resin content are unknown (Govindarao, 1980).
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6.13 Rubber

Shimomura et al. (1991) reported a density of 1160 kg/m³ and bending strength of 63.2 MPa for board made from rubber fiber.
6.14 Straw and Other Fibers

Properties of selected composite boards made from various agro-based fibers are shown in Table 9.13.

Table 9.13 Properties of Selected Composite Boards Made from Various Agro-Based Fibers

<table>
<thead>
<tr>
<th>Material</th>
<th>Ref.</th>
<th>Type of board</th>
<th>Density (kg/m²)</th>
<th>MOE (MPa)</th>
<th>MOR (MPa)</th>
<th>Compression strength (MPa)</th>
<th>Thickness swelling (%)</th>
<th>Noise reduction coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliage</td>
<td>1</td>
<td>Particle board</td>
<td>790</td>
<td>1,590</td>
<td>6.6</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Guat + sorghum</td>
<td>2</td>
<td>Cement board</td>
<td>530–700</td>
<td></td>
<td></td>
<td>10.8–11.0</td>
<td>13.7–14.5</td>
<td>0</td>
</tr>
<tr>
<td>Straw + reed stems</td>
<td>3</td>
<td>Insulating board</td>
<td>188–214</td>
<td></td>
<td></td>
<td>47.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Straw + polymers</td>
<td>4</td>
<td>Plastic board</td>
<td>520</td>
<td></td>
<td></td>
<td>47.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Straw + polymers</td>
<td>5</td>
<td>Particle board</td>
<td></td>
<td></td>
<td></td>
<td>0.39–0.54</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

* MOE is modulus of elasticity; MOR, modulus of rupture.

Some properties of straw composition panels are shown in Figure 9.13. Specifications for these panels are 97% pulped rice straw, 3% urea-formaldehyde resin, 0.98 specific gravity, and 2.0 mm (0.08 in.) thickness. Thickness swell and water absorption time values are unknown (Fadl et al., 1984).

7. CONCLUSIONS

Current production trends clearly indicate the increased use of both structural and nonstructural wood-based composite panels for many applications. Each material on the market was developed to provide the strength and other properties needed for a specific end-use. New uses are being developed continuously for these materials. The expanded use of composite materials has resulted in a significant reduction of production costs and greatly improved utilization of the fiber-based resource.

Strength and other property values presented in this report are basic values useful for comparative purposes and for developing improved products. Actual design values are generally available from code authorities, industry associations, and product manufacturers.
Economic considerations favor the selection of materials already in production. For specialized uses, new products with special strength and physical property values can be developed. The wood-or agro-based panels now on the market are the product of research in all phases of material selection, material preparation, and development of improved adhesives and manufacturing methods. Key areas in which further research could yield substantial benefits include improving strength and stiffness properties, determining optimum species or plant mixtures, improving durability and weatherability, reducing thickness swell, and improving methods for producing fire- and decay-resistant panels.

REFERENCES


Cherkasov, M., and Lodos, J., Use of furfural–urea resin for production of particle board from bagasse, Sobre Derivados de la Cana de Azucar, 3, 3 [Spanish], 1969.


Chow, P., Dry formed composite board from selected agricultural residues, World Consultation on Wood Based Panels, Food and Agriculture Organization of the United Nations, New Delhi, India, 1974.

Chu, B. L., Chen, T. Y., and Yen, T. Influence of the form of bamboo and particleboard on their bending strength and thermal conductivity, Forest Products Industries, 3, 291 [Chinese; English summary], 1984.


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Hesch, R., Particle board from sugarcane—a fully integrated production plant, Board Manufacture, 10, 39, 1967.


Paper and Composites from Agro-Based Resources

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