About 6 billion square feet of various types of wood-base fiber and particle panel materials are manufactured each year in the United States. Wood substance in one form or another is the principal raw material for all hardboard, particle board, and medium-density building fiberboard. About two-thirds of the insulating board produced also is wood base; the remainder is made from bagasse (waste from sugar cane), waste paper, or licorice root.

The total wood requirements for board manufacture based on plant capacity in 1961 are estimated at more than 10,000 tons (dry wood basis) per day. Total daily productive capacity in final board, including that from other agricultural fiber, is about 9,200 tons. Of this, about 2,700 tons are residues from some other type of forest products manufacturing operation. Principal sources of residue raw material for board manufacture include the following:

1. Waste veneer, cores, and clippings from the manufacture of plywood.
2. Slabs, edgings, and trim from lumber production.
3. Green and dry planer-mill shavings from lumber production.
4. Logs of little-used species or logging residues.
5. Sawdust, shavings, and whole-wood scrap from millwork production.
6. Scrap from furniture manufacture.

Both insulating board and hardboard manufacture originally developed around the utilization of a residue from some other prime conversion of log to product. Insulating board was first produced from the waste screenings of sulfite pulping, and hardboard was first produced from southern pine sawmill slabs and edgings. The manufacturers shifted to pulpwood when their production rose so high that these original sources of raw material were unable to supply their needs economically.

Manufacturing Processes

The conventional or wet-felting process for manufacturing board requires wood either in the form of chips for pulping or bolts for making groundwood pulp. Wood is reduced to fibers and fiber bundles either by grinding bolts of pulpwood or reducing pulp chips by exploding as in the Masonite process, by refining them in an attrition mill after steaming or directly without steaming or after treating in an Asplund-type defibrator. When washed, the fibers are carried in a water slurry and deposited on a wire of a Fourdrinier type, on a special cylinder-forming machine, or on a deckle-box former. To produce hardboard, the matted fibers either are pressed and dried between the platens of a hot press, or are dried and then pressed. Insulation board is produced when such mats are dried, generally in a continuous tunnel dryer, without further hot pressing.

Homogeneous medium-density building fiberboards are produced when binders (usually thermoplastic) are introduced into the fiber mat and the board is hot pressed to a density of 26 to 50 pounds per cubic foot. This supplemental binder is required to prevent the compressed board from

---

1 Originally issued under the title, "Board Materials from Sawdust and Shavings," revised in 1954 and issued under the title, "Board Materials from Wood Waste."

2 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Report No. 1666-21 (Revised May 1961)
swelling excessively during cyclic moisture exposures in service. A hardboard has sufficient natural rebonding because of the combination of pressure, temperature, and moisture during hot pressing so that it may not require additional binding material for some qualities.

In a variation of the conventional process for making hardboard, wood chips are reduced to fibers and fiber bundles with the same kind of equipment used in the conventional wet process. Instead of being conveyed by water, however, the fibers are refined and then partially dried, conveyed as an air suspension and formed into mats for hot pressing. This process is usually called the air felting or semidry process. It was pioneered by the Plywood Research Foundation of the Douglas Fir Plywood Association and by the Weyerhaeuser Company. Small amounts of synthetic resin are incorporated in the mat with this process, but the primary bond, as with the wet-felting process, is produced by the interfelting of fibers and the natural bond produced during hot pressing.

In another process, resin-bonded particle boards are manufactured by bonding fractions of wood substance together with synthetic resin glues. This type of board is showing the most rapid percentage production increase. Fractions of wood that are presently being used in the manufacture of particle board or that could be used include granules, flakes, strands, curls, slivers, and fibers. These particles are produced by mechanical equipment ranging from simple hammer mills to special tools for cutting flakes. Planer shavings or sawdust used for particle board are usually reduced to a uniform size in hammer mills. Boards made of planer shavings are commonly called "shavings" board. Those made of substantial amounts of sawdust are usually fine textured and may be called "granule or fines" board. Those made from specially cut flakes are called "flakeboards." The particles are mixed with adhesives and formed in pans or similar equipment. They are then compressed into panels, and the resin binder is cured in hot presses.

In one of the early attempts to produce a satisfactory building board, Portland or other cement was used to bond wood excelsior into panels. In the manufacture of boards of this type, the principal difficulty is that the soluble sugars and hemicelluloses in the wood have an inhibiting effect on the setting of the cement. Tests have shown that these soluble materials also reduce the final strength of Portland-cement mortars. The addition of small amounts of calcium chloride to the water in the mix overcomes the retarding effect of the sugars and hemicelluloses and restores most of the strength. It may also be possible to leach out the more extractable hemicellulose by treating the wood wool or excelsior with limewater before mixing the cement and the wood. In use, absorbed water may also cause swelling of the wood and some disintegration of the bond. The successful products of this type are made of specially cut wood wool and excelsior. Special additives are employed to reduce swelling of the board caused by absorption of moisture. Production of this kind of board is increasing but total production is relatively small.

Effects of Kind and Form of Raw Material

It has been demonstrated to be technically possible to make any kind of fiber or particle panel material from any species of wood in almost any form. Some forms or kinds of wood, however, are not used so much as they might be because they result in a finished product that is undesirable from a merchandising standpoint, are impractical from a manufacturing standpoint, or are uneconomical from a handling standpoint. This is particularly true when residues are used.

Bark is a good example. Although substantial amounts of most kinds of bark can be included in raw material for a board product without lowering its strength and physical properties so much that the finished product does not meet use requirements and specifications, little bark is included in either fiber or particle board furnishes. This can be because of any one or a number of the following:

(1) The dirt and grit that are almost always present in bark rapidly dull the knives in chippers and flakers. Most manufacturers, consequently, find it more economical to use raw material free of bark for this reason if no other.

(2) In pulping processes, bark may require different conditions than wood.

(3) In wet furnishes, foaming and slime problems are increased.
In particle processes, bark components may be either "stringy" or "flaky." This creates problems in screening, resin distribution, and mat formation.

In raw material mixtures containing both bark and wood, production problems develop when ratios of bark to wood are not constant. This ratio is not constant, for example, in most instances where residues such as slabs are utilized.

Bark components are dark colored and show up in the finished boards either by darkening the entire board or as dark-colored flecks.

Buyers of insulating and particle boards associate light color with quality and they often demand a uniformly light-colored product even when the purpose for which the material is to be used imposes no such requirement.

The only nonsolid wood form of residue that is used in substantial amounts in board manufacture is green planer shavings. In the western United States, the lumber mills have available sufficiently large quantities of green planer shavings that economically sized particle board plants are possible either at a single sawmill or within an economical hauling distance of two or more sawmills.

Green planer shavings are hammer milled to break them into more sliver-like components for particle board. Because of their higher moisture content at the time they are formed, the green planer shavings are damaged less by the planer head than are shavings planed from dry wood. Commercial planer heads are designed solely for their function of removing wood to convert a rough surface into a smooth one, with no thought of the shaving itself. Research at the Forest Products Laboratory indicates that the quality of planer shavings for particle board can be improved considerably by a modification of planer heads, particularly if a slightly less smooth surface on the lumber is acceptable.

Dry planer shavings are used to some extent for particle board, but fines which must be removed by screening are produced in greater quantity by hammer milling the dry shavings than the green ones. The properties of a board made from the dry shavings are usually lower than those of a board made from green shavings, other things being equal.

It is a rather common concept that sawdust is a suitable raw material for board. Because it has little other value, many people suggest the possibility of making particle board from sawdust. The synthetic resin binder may be the most expensive raw material used in the manufacture of particle board even though only 6 to 10 percent of it, in terms of total board weight, may be required. More resin is required with poorly shaped particles like those from sawdust than with better formed particles from some other kind of raw material.

In pulping processes, sawdust and shavings are less suitable than pulp chips because of their bulk per unit of fiber. They tend to plug conveyor systems and digesters. Some fiber from shavings and sawdust is blended into furnishes for insulating board. At present, some paper is made from specially produced sawdust. Yields are lower than for conventional pulp chips, but indications are that it is economically feasible to use this type of sawdust and that this sawdust might be used for other products.

**Economics of Plant Size**

Insulation board plants usually must be large-capacity installations to be economical, because of the cost of continuous dryers. There may not be sufficient whole-wood waste, such as slabs, edgings, and end trim, within an economical hauling distance to justify the installation of conventional insulation board plants that would be competitive with existing plants using pulpwood.

Conventional wet-felting and the new air-felting hardboard mills are apparently economical for installations having sources of wood for fiber in multiples of about 35 tons per day. Several of the new hardboard plants are based on sources of wood from some other lumbering operation. This type of plant has one multiple-platen press, and the capacity of the other equipment in the plant is designed around it. Such a plant, with a 4- by 16-foot, 20-opening press and using the usual press cycles required for consolidating hardboard, will use about 70 tons of raw wood each 24 hours for board production. Additional wood can be used for fuel to generate power to operate refiners and other equipment used in the manufacture of the board and to provide steam to heat the platens of the hot press. Fuel requirements amount to about 2 to 3 tons of wood waste per
ton of board. It may be feasible in such an operation to select clean, barkfree wood for raw material and to use dirty or unbarked wood, shavings, and sawdust for fuel. Some installations can and do use unbarked wood as raw material for board.

In small plants, the resin-bonded particle boards can be made more economically and competitively than fiberboards made from fibers produced by pulping procedures. A successful particle board operation need have a daily capacity of about 10 tons. Plant and equipment costs are much lower than for those using conventional processes. Press cycles are shorter per unit of thickness; consequently, thicker boards can be made more economically. Many feel that the wet- and air-felted boards of a density that requires hot pressing will continue to find their greatest use for products 1/4 inch or less in thickness, and the resin-bonded particle boards will find their greatest use in thicknesses of more than 1/4 inch.

The influence of cost of sales of finished product on economical size of plant should be considered. A small hardboard plant with a capacity of 35 tons per day (that is, with a 20-opening, 4- by 8-foot press) may be economical from a cost-of-manufacturing standpoint, but it may not be so economical when the costs of maintaining a sales force are included.

This also is true when the smaller sized particle board plants are considered. The most successful small plants are captive plants; that is, the board is utilized in the same factory where produced, going into furniture, cabinet work, or some other finished article.

The most successful manufacturers of board products appear to be either those with plants of large capacity or those making specialty products. There is an obvious advantage for producers who can also sell other products to the same customer. Mixed-car shipments broaden the base of operations considerably.

It is not possible to present a "formula" type answer to the feasibility of a venture into board manufacture. No two situations are alike. In each instance, a careful analysis is required of both the technical and the economic possibilities.

Primary Manufacture of Fiber or Particles

Well-developed equipment that will reduce whole wood to fiber and fiber bundles suitable for conventional fibrous insulation and hardboard is available from several manufacturers who specialize in pulp-making machinery. The chippers that are used to reduce whole-wood waste or waste veneer to chips are the same as those used to produce chips for pulp.

Grinders are used in most insulation board plants to reduce bolts of pulpwood to groundwood pulp and to eliminate the need for chipping. They are of the same kind used for producing groundwood pulp for paper. Plants that use small pieces of wood, chips, or waste veneer, however, reduce chips mechanically in disk-attrition mills after some type of steaming or softening of the chips. Asplund defibrators, continuous steam cookers, and the Masonite guns are types of units used to soften and reduce the chips to fiber. Sprout-Waldron and Bauer disk refiners are examples of the attrition mills that are used.

Particles for the resin-bonded wood-particle boards are made mechanically by various kinds of mills and cutters. Hammer mills are often used for this reduction of wood to particles. The equipment used to reduce wood to particles is not as well developed as equipment used to make pulp for the fibrous, felted boards.

The milling that produces particles should damage the fibers as little as possible. Particles with large amounts of damaged fiber impair the strength of boards, because many of the individual fibers have microscopic fractures. For example, boards manufactured from dry planer-mill shavings are usually inferior in strength to boards produced from green planer-mill shavings. This can be explained partly by the lesser amount of damage done to individual fibers in shavings planed from green lumber than from dry lumber.
After milling, particles are screened so that fines are usually removed and oversize material can be remilled. Particles of reasonably uniform size are usually required for satisfactory board, although some products have a layer of fines on each surface for smoothness of finish. If particles much different in size are used in a resin-bonded particle board, problems of segregation develop, because the finer particles tend to sift down through the coarser particles. Fines also require more resin for proper bonding than do coarser particles, because they have more surface area per unit volume.

**Resin Requirements**

Conventional insulation boards and hardboards require little or no resin for proper bonds and strength. Usually rosin and alum are added to insulation boards as sizing during manufacture to decrease water absorption. Asphalt may also be added to increase the wet strength of boards that are made to be used as sheathing, or under other severe exposure conditions. Some manufacturers of wet-felted hardboard add up to 3 percent of phenolic resin to increase the strength and water resistance of certain grades of board. The resin is precipitated on the fibers while they are in the water slurry before the board is formed. The resin is cured in the hot press. The resin increases strength and water resistance and reduces the rate of shrinking or swelling with changes in moisture content.

Air-felted hardboards may require some added resin for an adequate bond. A phenolic resin, in dry powder or liquid form, is added to the fibers just before the mat is formed. Mixing is accomplished in separate blenders or in the forming equipment. Particles of the dry resin adhere to the fibers which are slightly damp (15-20 percent moisture content by weight); consequently, segregation of fiber and resin is not usually a problem. Liquid resins are usually sprayed on the fibers.

Larger quantities of resin are required to bond particle boards together than are needed for insulation boards and hardboards. The primary bond in the particle boards is produced by the cured resin. When optimum strength of finished board is required, sufficient resin must be used to provide the bond for that part of each particle which is in contact with other particles. The amount of resin required per unit volume of board depends on the size and shape of the particles. Small particles have more surface per unit volume, hence may require more resin to coat the particles effectively. Because the resin is by far the most expensive ingredient in a board, the selection of an optimum particle is most important. The amount of resin required is less when particles of proper size and shape are used.

Two kinds of synthetic resins are usually used for particle boards. Because they are lower in cost than the phenolic resins and are light colored, urea-formaldehyde resins are used for boards that are made for interior applications where exposure to moisture is not a problem. Urea resins, however, are not usually durable under protracted exposure to high temperature or shorter exposures to high temperatures in the presence of moisture. The phenolic resins do not disintegrate under such severe exposure and therefore provide more permanent bonds. The phenol-formaldehyde resins, consequently, are used to bond boards that will be used outdoors or for uses where exposure to heat or moisture is a factor.

Satisfactory resin-bonded particle boards are being manufactured with a resin content comprising 6 to 10 percent of the dry weight of the final board. Lower percentages of resin are possible when the most efficient particles, such as flakes, are used. The use of surplus amounts of resin beyond what is needed for the bond does not add strength to the board. Some properties, such as water resistance or surface hardness, may be increased, but not in proportion to the cost of the resin. Resins are usually applied to the particles in liquid form, although it is possible to use powdered resin. Liquid resins are usually sprayed on the particles. Uniform mixing is accomplished by tumbling the particles in a drum or by mixing them in a pugmill-type mixer or a continuous screw-type mixer of the kind used for mixing dry chemicals. The moisture content of the particles must be controlled while the resin is being added, so that resin application will be uniform.
Pressing, Drying, and Curing Equipment

Insulation board products are roller or screen pressed to consolidate the board and to squeeze out excess moisture prior to drying, but they are never hot pressed. The maximum density of board that can be made without hot pressing, such as is needed for hardboard, is about 26 pounds per cubic foot. Drying of insulation board is done in continuous tunnel dryers at maximum temperatures of about 500° F.

Multiplaten hot presses are usually used to compress the mat and to cure the resins in conventional hardboards and resin-bonded particle boards. These are equipped with automatic loaders and unloaders to reduce labor costs and to keep to a minimum the time that the press is inoperative. Hot presses are usually of the 4- by 8- or 4- by 16-foot size. The maximum number of openings in each press is 20. For conventional wet-process hardboards, presses with platen-pressure capacities of about 1,000 pounds per square inch or less are sufficient. The exact maximum pressure used depends on the density of board desired and the pressing cycle employed. Higher platen pressures (1,500 pounds per square inch maximum) may be required for hardboard made from dry fiber mats than for board made from wet mats.

Platen pressures for pressing and curing of the resin in the particle boards are dependent upon the density desired and the type of particle used. For a series of experimental boards made from hammer milled, green planer-mill shavings, the following pressures were used to obtain boards of different specific gravities:

<table>
<thead>
<tr>
<th>Platen pressure</th>
<th>Specific gravity of finished board</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 P.s.i.</td>
<td>0.60</td>
</tr>
<tr>
<td>500 P.s.i.</td>
<td>0.80</td>
</tr>
<tr>
<td>1,000 P.s.i.</td>
<td>1.00</td>
</tr>
</tbody>
</table>

In some particle board plants, an extrusion press is used instead of a multiplaten press to form and compress the board and cure the resin. The principal advantage of the extrusion press appears to be the continuous operation. A particle board manufactured in that way has definite directional properties, because many of the individual particles are oriented so that their long axis is perpendicular to the extruded direction of the panel. The board is therefore weaker in one direction than in the others, which may be disadvantageous for some uses. Cost of equipment per unit of capacity may be less for extrusion than for multiplaten hot presses.

A continuous press developed in England is being offered for sale in the United States. While little is known of its actual operation, this press has the obvious advantage of making the process continuous and uniform. Its disadvantages appear to be higher initial cost and possibly higher costs of maintenance because of many moving parts.

Treatment After Manufacture

Whatever moisture is left in the boards after pressing is near the center of the board. The average moisture content of the board also may be less than that required in most uses; therefore, boards may be humidified after manufacture and before they are shipped. Boards are usually placed in the racks in humidified chambers, so that moist air can get to all surfaces. The humidification has the added advantage of relieving stresses produced in the boards during pressing and drying.

Some boards are treated after manufacture to improve appearance or other properties. The treatment may range from simple dips in moisture repellents, asphalt, or similar material to the oil tempering used on some hardboard. When hardboards are tempered, they are passed through a bath composed of drying oils and other chemicals. The boards are then baked until the oils diffuse through the board and are chemically stabilized. Tempering improves both strength and water resistance. It is a common European practice to heat-treat hardboard immediately after hot pressing it to increase strength and decrease water absorption.

Final finishing may be done in many ways. The boards may be painted, scored, sanded, or embossed to provide the desired surfaces and patterns for many special uses.