DEPARTMENT OF INDUSTRY
OTTAWA CANADA

A STUDY OF THE PARTICLEBOARD INDUSTRY

F O R E W O R D

This report is intended to provide a better understanding of the particleboard industry with respect to its past, present, and future and to provide background information to persons contemplating entering this field.

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D E F I N I T I O N

Particleboard is a formed panel consisting of particles of wood bonded together with a synthetic resin or other added binder. It is manufactured from logs or other wood material, which is reduced by cutting, hammer-milling, grinding, etc., into flakes, shavings, slivers, etc., that are classified by size, dried to a uniform moisture content, mixed with a binder, mat-formed, compressed to uniform density and then cured under controlled heat and pressure.

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HISTORY AND DEVELOPMENT

During the late 1930's, scientists in Germany began working on the idea of forming from disintegrated wood waste a board-like product that would retain some of the properties of wood without the drawbacks and disadvantages of the ordinary board. The industry was born in Germany, where the furniture manufacturers could utilize their own waste products in the form of sheet material of various thicknesses. The first commercial plant began operating in Germany in 1941 and others soon followed as integrated captive operations close to the major forest products plants where transportation and handling could be kept to a minimum and close supervision of all operations could be maintained.

When first developed, it was seen as a convenient substitute for sawn lumber at a time of shortage, but it soon became a material of great value in its own right, and one in which the profit possibilities were considerable since there was very little timber wastage. Modern captive plants follow much the same pattern, with plant capacity designed to suit the kind and volume of available raw material, and type and volume of particleboard required by the parent plant for the fabrication of its major products. One of the major problems of a captive plant is a scarcity of waste, which may make the particleboard operation uneconomical, especially if the use of particleboard in manufacturing the primary products progressively cuts down the amount of mill residue available.

Gradually, particleboard plants were set up by sawmills, planing mills and other plants which had a waste problem, but did not use the board in manufacturing their major products. Problems arising from dependence upon wood residues have tended to move the particleboard plant out of the integrated operation, and they have become independent organizations using roundwood, or sometimes a combination of roundwood and mill residues.

The first plant in the United States was built in 1948. Canada's first plant commenced production in New Brunswick in 1949. Quality demands by the consumer, particularly the furniture industry, have brought about a large increase in the use of roundwood as a raw material, where the flakes must and can be accurately machined.

MANUFACTURING PROCESS

Wood Preparation

Unless the raw material is in the form of waste from a previous woodworking operation, a certain amount of preparatory work is generally required. Barked wood can be made into particleboard, but there are reasons why accepted roundwoods should be debarked. Small bark particles utilize more resin than flakes, shorten the life of chipper blades, and detract from the appearance of the finished product. In most cases it is advisable to pass the timber through a metal detector to prevent damage to the expensive chipping machines.

One of the most important factors to be considered is the moisture content of the wood, as this has considerable influence on the quality of the chips. Moisture contents above the fibre saturation point are required for best results, with a minimum of dust or splinter wastage. On the other hand, if the moisture content is too high, drying costs become excessive.

The most common types of debarker are:

(1) a drum machine where the debarking is effected by converting externally applied mechanical forces into friction between the logs, and

(2) by applying rotary force directly to the log surface.

Chip Preparation

Initially the manufacture of particleboard was a way of utilizing waste shavings more profitably than as a low class fuel. But as soon as early production had shown the potentialities of the product, attempts were made to produce dimensionally controlled chips. At this stage of development, the properties which attracted most interest were bending strength and the related modules of elasticity. In general (and within limits) board strength increases with rising board density, decreasing chip thickness, increasing chip length, decreasing raw material density and increasing resin content. It was soon discovered that prepared chips rather than planer shavings, or other waste, would give the same bending strength at a lower density, and with a lower resin content.

With the advent of prepared chips came the manufacture of multilayer boards, where the chips of each layer could be accurately controlled. This produces boards with smooth hard surfaces of higher density than the core, and results in good surface properties and adequate mechanical performance at a lower cost.

The chipping machines can be divided into four broad classes.

1. Chipping machines for production of surface or core layer chips, for operation with the best type of raw material (chip thickness and length can be obtained).
2. Coarse chippers for use with low class waste for conversion into core chips (chip thickness only can be set on these machines).

3. Disintegrators for the production of chips from low class waste of different types and shapes.
4. Mills for grinding of planer mill shavings (width reduction) of prepared chips from class 1.

Drying

An efficient dryer is required to ensure that an adequate amount of heat is provided and that the chips remain in the dryer long enough for evaporation of the required quantity of water to take place. If a solid remains in contact with air at a certain temperature and humidity, it will reach a moisture content known as the equilibrium moisture content under these conditions. The equilibrium moisture content of a fibrous material such as wood, varies over a wide range as the properties of the surrounding air change. The minimum moisture content of chips leaving the dryer is determined by the humidity and temperature of air at the dryer exit, and because the rate of drying decreases as the equilibrium is approached, commercial dryers usually aim at a final moisture content above the equilibrium. There is a wide range of dryers available today--the most common being:

(i) rotary drum dryers
(ii) suspension dryers (vertical air flow through screens)
(iii) contact tubular dryers.

Dryers can be heated indirectly by steam or hot water, or directly by gas or oil. The indirect method reduces the fire risk, but also the thermal efficiency. Some dryers are designed to perform a double function, i.e. reducing the moisture content, and size separation of chips. The main factors to be considered in the selection of a dryer are raw material dimensions, required uniformity of moisture content, power consumption, thermal efficiency, safety considerations, damage to the material, suitability to plant layout, and existing power and heat sources.

Resin Mixing

With the cost of resin frequently amounting to over 30% of the manufacturing cost, the need for good mixing equipment is very important and, since the mixing process is vitally dependent on the feed of chips and resin in the correct proportions, it is useful to summarize the methods by which this balance can be maintained.

One method is to feed chips over a belt weigher, the signals from which vary the speed of the resin pump. A second method is having the resin flow set at the required rate with a belt weigher acting on a storage bin to maintain the chip flow. A third method employs a batch weighing machine which releases a fixed amount of resin for a fixed amount of chips. A chip resin mixer consists essentially of a longitudinal tank-like piece of equipment with a shaft running down its centre, to which are attached mixing arms for tumbling the chips, while the liquid resin (atomised by compressed air or centrifugal force) is sprayed on the chips. The resin coated chips usually pass from the resin mixing machine to a conveyor for further processing. It is important that apart from being good mixers, these machines should be constructed for easy cleaning.

Chip Conveyors

The two main methods for chip transport within the mill are by mechanical and pneumatic conveyors. Mechanical conveyors may be the flat belt chain carrying scraper blades or screw conveyor of various designs. Pneumatic conveying system (fans and cyclones) may be of high or low pressure design although the low pressure system is the most common.

Storage Bins

Storage bins are used to control the flow of materials from one operation to another and they may do this in a continuous or batch process. The storage bin should give uniform flow rates when the bulk density of the material remains constant and should be easily adjusted when changes of bulk density take place. When practical, these storage bins are elevated to reduce space requirements and to take advantage of gravity flow in dispensing the materials to the machine it supplies. A thorough knowledge of the material is essential in bin selection as the behaviour of the discharge mechanism is greatly affected by chip properties. The bin is usually equipped to discharge the material in metered quantities compatible with the capacity of the unit which receives it.

Another important purpose of storage bins in a particleboard system is to act as a buffer between two phases of production-a breakdown in any machine will not interfere with production through the balance of the system unless, of course, the breakdown persists until the buffer supply of material is exhausted.

Another benefit is labour cost reduction. If the storage bins possess two or three times the capacity of the remaining portion of the system, sufficient particles may be prepared in one shift to supply the process for two or three shifts.

Some companies have several storage bins, each containing a different class of chips, and they can manufacture a variety of boards or change the composition by switching the flow from one bin to another.

Mat Formation

The preparation of a consistently uniform carpet of resinated chips ready for pressing is probably one of the most vital parts of a particleboard manufacturing process. A lack of uniformity in chip distribution will not only lead directly to density changes and variations in physical properties, but these variations may be further extended by compression and curing differences. It is this overriding importance of uniform distribution which has set a practical limit to chip dimensions because larger chips which are potentially capable of giving better mechanical properties cannot be distributed evenly enough. Most mat-forming machines operate continuously and deposit a carpet of chips either on a belt or on a series of adjacent caul plates. A machine moving over stationary belts or caul plates can produce similar results. In smaller plants multi-layer boards can be produced on one or two mat-forming stations by having the caul plates pass under the laying machines first in a forward, and then in reverse direction, before proceeding forward to the press.

For multi-layer boards, there are usually several separate chip flow lines, each to a separate mat laying station. Layers of chips are deposited successively surface-core-core-surface on the belt or caul plate. The material is deposited on one or more belts within the machine, and the discharge is volumetrically controlled by levelling rolls. In some machines the chips are fed over rotating discharge rolls which throw the heavier particles forward in the direction of rotation, thus giving a grading effect within each layer. Other machines are designed to receive one flow line of chips and to grade the chips according to size and weight before depositing them on the caul.

One method is to pass the chips over a system of vibrating screens where the fine chips are moved to either end and are laid first and last on the mat. A second method feeds the chips on either side of a central air distribution mechanism which is specially designed to guarantee uniform air flow. The horizontal air throws the finest particles furthest along the belt whilst the heaviest particles drop almost vertically. The resulting buildup of the mat will have the finest particles on the surface and the largest particles in the centre of the mat. This is a graduated layer. In view of the importance of accurate mat laying, most conveyor systems have weighing machines immediately behind the mat-forming station. Mats which do not conform to the weight specification are rejected and the material is returned to the chip flow to be used over again.

Presses

For the purposes of this section, we will be concerned with flat presses only--continuous and extrusion systems will be discussed elsewhere in this report.

There are many methods of getting the mat from the forming station to the finished board, but we shall briefly touch on those most widely used. Most systems utilize a pre-press which is usually a single-opening, hydraulic, cold press, the platens of which are approximately of the same dimensions as the mat conveyor which is usually a caul plate or a continuous steel or rubber band. The pre-press operation diminishes the thickness of the mat, thus reducing the maximum opening required for each main press daylight, and the consolidation of the mat facilitates subsequent transport.

In systems where a continuous mat is laid down on a steel or rubber band, the pre-press operation may take place by having the mat pass between compression rollers. Where a continuous mat is used, cut-off saws travelling at the same speed as the mat, cut the mats into the desired lengths, and these are usually picked up by accelerated conveyors which pass them on to the main press loader. Some presses have side blocks which give the mat firm edges and produce very little waste when the mat passes the vertical edge trimmers. The mats leave the pre-press and approach the main press. The main press may be single opening or multi-opening. The mats may be on a caul plate which passes through the main press, or the caul may be removed immediately prior to the mat entering the press. The mat may reach the main press on a conveyor belt which passes through a single opening main press, or it may discharge the mat immediately prior to its entering the press. If it is a multi-opening press, then the mats are deposited in a loader (with or without cauls) containing the same number of shelves as there are openings in the main press. When the loader is filled, it is pushed hydraulically into the main press, releases its mats, and is withdrawn. After the mats are pressed, the procedure is reversed as the unloader receives the mats from the main press. Presses may be simultaneously closed, or each opening closed in succession. The press cycle is co-ordinated so that fresh mats are ready to fill the hot press when the press has completed its cycle. The platens are usually heated by steam, hot water, or oil.

Board Finishing

After leaving the press, boards are generally stacked for varying periods before the finishing operation is begun. During this period—referred to as after-cure, aging or conditioning—chemical and physical changes take place in the board. The board seeks moisture equilibrium with the surrounding air. If equal to or below the surrounding air, it will lose moisture on cooling, and will have to regain the moisture required to bring it to equilibrium with the surrounding air. Alternatively, if the board leaves the press at a slightly higher moisture content so that no moisture has to be regained after cooling, conditioning will have been speeded up considerably. Most plants have a board weighing machine which rejects boards not conforming to specifications, and a metal detector which stops the conveyor if a board contains a piece of metal.

The two main mechanical operations in finishing lines are cutting to size and surface finishing. If cross cutting of a moving board is required, this is done by either clamping a cross-cut carriage with a travelling saw to the board, or by letting the saw run at an angle to the board, with such a relation between angle and board speed that a straight cut results.

Planers, drum sanders, and belt sanders are the three types of machinery available for surfacing boards. The selection of equipment must take into account the thickness variations of the raw board and the surface finish required. A planer gives a lower quality finish but is better fitted to deal with substantial thickness variations. Drum sanders are frequently employed where the raw boards have a fairly uniform thickness, and finishing requirements are not exceptionally high. A high class finish is obtained by wide belt sanders, and where there are variations in thickness, a combined drum and belt sander is frequently used. As labour became expensive, complete finishing lines with a high degree of mechanization were developed, in which saws and sanders were combined with turning devices and automatic board feeders and stackers.

Check List for Particleboard Plant Trouble Shooters

Problems and Solutions in Multi-Platen Operations

Cause	Correction
	Problem: Blows or Blisters
Press time too short	(1) Increase cycle.
Moisture content of particles too high	(2) Do not use high hot-press temperature to attain short pressure unless moisture content of mat is carefully controlled.
	(3) Drier control off.
	(4) Resin treatment wrong.
	(5) Remove sufficient water from resin mix to adjust to proper moisture content.
	(6) Use higher solids resin.
Non-uniform moisture content (wet spots)	(7) Balls of resin wax and chips have carried through from blender to mat causing high moisture areas. Clean blender more frequently. Remove excessive dust to prevent build-up in blender.
Press temperature too high	(8) Reduce temperature--290°-300°F is adequate for most operations.
Presence of defects in the mat	(9) Non-uniform mat moisture caused by wax and resin balls, water on caul or mat, surface being water sprayed unevenly.
Water logged platen	(10) Check steam pressure and steam traps.
	Problem: Precure (Loose Surface)
Adhesive mix too reactive	(11) Change catalyst to a less reactive formula.
	(12) Use a less reactive resin.
Assembly time too long	(13) Keep less blended material ahead of press.
	(14) Do not allow mats to remain close to press longer than usual press cycle.
Slow closing of press	(15) Increase pump capacity and flow rate of oil to ram.
	(16) Install simultaneous closing equipment.
Hot particles	(17) Hold flakes in silo longer.
	(18) Air cool particles prior to blending.
Hot cauls	(19) Water spray cauls to reduce temperature of metal faster.

Cause	Correction
Press temperature too high	(20) A press temperature of 325°F will cause more pre-cure than a temperature of 290°-300°F.
Inadequate blending	(21) Poor resin coverage will cause surface flakes or particles to appear loose due to lack of adhesive.
	(22) Improve blending by better spray system having automatic cleanout needles and installation of a large blender enabling greater surface area exposure to spray. Maintain constant resin temperature and resin viscosity.

Problem: Warpage

Cause	Correction
Non-uniform density	(23) Improve mat forming equipment.
	(24) Use a longer assembly time between blending and forming, thereby reducing stickiness.
	(25) Keep particles from compacting in surge bin at forming machine.
Particles sifting down in mat	(26) Produce a mat having less variation in particle size.
	(27) Dust and fines that absorb resin settle out resulting in an unbalanced board.
Press temperature different between platens	(28) Unequal temperature caused by faulty steam trap, water logged platen or obstruction in line.
Over-curing in the hot press	(29) Remove panels as soon as press opens.
	(30) Excessive heat causes drying out of panel surface when left in press longer than necessary.
Improper conditioning	(31) After cure is important to enable moisture equalization.
	(32) Uniform exposure of panel surface to humidification until E.M.C. of use is obtained.

Problem: Weak Board

Cause	Correction
Improper resin treatment	(33) Determine resin treatment by checking wood weight used in relation to resin solids treatment.
	(34) Low resin treatment (below 6%) will be cause for weak board.

Cause	Correction
	(35) A Kjeldahl nitrogen test will indicate actual resin treatment but requires time and a laboratory to conduct.
Wax treatment too high	(36) Determine wax treatment by checking wood weight used in relation to wax. A treatment of higher than 1% should be avoided.
Insufficient cure	(37) Resin reactivity too slow. (38) pH of wood or wax affects rate of cure. (39) Temperature low due to steam pressure or steam traps.
Low density	(40) Mat forming machine needs adjustment. (41) Check accuracy of mat scale. (42) Press mat closing to stops.
Inadequate blending	(43) Examine coverage of particles by staining. (44) Increase "dwell" time in blender. (45) Check nozzle for spray patter and delivery.
Resin slow in reacting	(46) Resin formula buffered excessively. Adjust with catalyst.
High moisture	See 2-6 above
Low moisture	(47) Low moisture retards press closure to stops. This results in lower heat transfer to center of board and creates "spring back" due to lack of cure. (48) Maintain proper moisture by careful dryer, resin and/or wax treatment control.

Problem: Weak Edges

Cause	Correction
Poor forming	(49) The mat must be formed uniformly to the edge of the panel with sufficient trim allowance.

Problem: Resin Spots

Cause	Correction
Blender needs cleaning	(50) Build-up in a blender is caused by dust and resin collecting in "dead" areas.
Dust % high	(51) Dust is difficult to screen out as it is electrostatically held to larger particles. (52) Air separation is efficient in removing dust.

Cause	Correction
Problem: Soft Centres	
Insufficient cure	See 2-6, 33-35, 46, 47. (53) Maintain correct moisture, resin treatment, heat on press and cure cycle.
Problem: Dense Board	
Forming machine needs	(54) Decrease mat weight by reducing thickness.
Mat scale inaccurate	(55) Check scale accuracy by loading scale with a known weight.
Problem: Thick and Thin	
Uneven mat formation	(56) Adjust levelling screws. (57) Check for bin "bridging." (58) Maintain sufficient material in forming machine to permit uniform feed to levellers and cauls.
Platens warp under pressure	(59) Thin platens will warp under pressure when mats vary in density. (60) Platens 3" thick are recommended to minimize this difficulty.
Chips squeeze out onto stops	(61) Space between mat and stops needs to be sufficiently wide to prevent excessive "flow out" over the stops. (62) Mechanical edge compaction of mat will minimize "flow out."
Problem: Wedge Shaped Boards	
Lack of stops	(63) Some presses operate without stops on each platen. Uneven mat formation and temperature will affect panel thickness.
Uneven mats	(64) Forming machine out of adjustment.
Problem: Uneven Density	
Uneven mat formation	(65) Forming machine needs watching and adjustment.
Problem: Excessive Formaldehyde Odor	
Inadequate ventilation	(66) Install stronger motor in hood and extend hoods to collect fumes that escape in plant.
Humid weather	(67) Correct by drying wood to lower moisture or a resin having less water.
Resin and/or catalyst unsuitable	(68) Obtain resin with lower free-formaldehyde. (69) Use a catalyst system that reacts with free-formaldehyde.

Cause	Correction
Higher than usual moisture	(70) Dry wood to a lower moisture content. Use higher solid resin.

Problem: Indentations

Cause	Correction
Defective equipment	(71) Keep cauls clean, smooth and waxed. (72) Platen surface should be treated to prevent sticking and air blown clean of chips between loads.

Problem: Layering

Cause	Correction
Surface of board densified	(73) Allow heat to penetrate into centre before reaching stops or maximum pressure.
Heat softens wood permitting consolidation and crushing of surface particles. Board center being slower to heat will not compact as readily, resulting in more voided and lower density area.	(74) Use R. F. heat in conjunction with steam heat.

IMPORTANT PROPERTIES OF PARTICLEBOARD

Density

The density of particleboard is important for considerations of weight. For example, doors should not be too heavy due to the danger of screws and hinges giving way.

Thickness Variation

Variation in thickness must be kept low for satisfactory veneering.

Machinability

Poor machinability may result in excessive wear on tools as well as tearing or breaking of the cut edges.

Screw Holding (edge of board)

Most boards have a dense face and a relatively porous interior and the screw-holding ability of the board is concentrated in the surface.

Tensile Strength Perpendicular to the Surface

This is the measure of the tendency of the board to delaminate, and is very important where screws or dowels are used.

Movement Due to Humidity Changes

Movement can cause warping and cracking of joints.

Tendency to Telegraph

Important where thin veneers or laminates are bonded to the board.

Swelling as a Result of Wetting

Important in the manufacture of furniture, and kitchen or bathroom wall systems--the addition of wax in manufacture reduces the water absorption of a board.

Bending Strength

An important property where the board is used in construction.

Advantages over Wood

1. The variation of strength in different directions is small and the absence of many natural defects that natural wood contains (shake, splits, knots, pitch pockets).
2. The surface is smooth and hardness can be controlled.
3. It is beetle-proof, rat-proof and resistant to decay.
4. The change in dimension due to changes in temperature or moisture is small.
5. Variation in sound absorbability is small.
6. Resistance to fire, sound transmission, heat loss and electricity is better than that of wood.

PARTICLEBOARD SYSTEMS

A well known European consultant estimates that there are about 450 particleboard plants in all countries and that they use 40 different manufacturing systems. Although some of these systems are basically the same, minor differences in machine manufacture or performance enable the planning engineering company to attach their own label to the finished product. The variations within the system are dependent on many things, such as type of raw material, type of finished product, amount of capital invested, type of binder used, etc. Each plant must be considered individually to suit a particular customer's needs.

Originally, the engineers and wood technologists who designed the first particleboard plants approached foundries to have the machines custom-made to their particular specifications. As soon as the larger machinery companies, particularly the press manufacturers, became experienced in manufacturing and installing particleboard machinery, they took over the design and installation of complete plants and this gave rise to many new systems. These machinery manufacturers were most successful in highly developed countries where plenty of skilled technical help existed, as well as, manufacturers of ancillary equipment such as blowers, motors, conveyors, etc. Independent consulting firms have been quite successful in the underdeveloped countries of Asia and Africa, where the purchaser wants the complete package in running order.

A prospective producer may have some difficulty in deciding on which system of production he should use. Each has certain desirable features, and the first thing to determine is what raw material is available and what type of finished product is required. Thirty-five per cent of the world's particleboard is manufactured under three systems in 168 installations. One of these systems produces ten per cent of the world's production in only 18 plants.

The various manufacturing processes might be classified in several ways but, since the press is the heart of the plant, the industry can be divided into three main press types:

(1) the platen hot press,

(2) the extrusion press, and

(3) the continuous press.

The platen hot press is the most common. It may be a simple, single-opening press or a multi-opening, simultaneous closing press, with up to 24 openings, with automatic loaders and unloaders.

The extrusion press is usually a vertical press where chips are forced by a ram through a narrow space heated by platens. The chips end up in the board perpendicular to the surface of the board.

The continuous press is fed by an endless steel band which carries the mat through the press. The mat passing through the press is confined between two moving bands having been first preheated by a high frequency coil.

There are relatively few installations of this type in the world, and the consensus of opinion is that further refinements are needed although the theory of a continuous flow through the main press intrigues many design engineers.

Some press manufacturers equip their presses with simultaneous opening and closing devices, while others do not. It is generally agreed that it is very difficult to produce boards of uniform quality on a multi-opening press (over 10 openings) without simultaneous opening and closing. If the press is not simultaneous closing, then the first board into the press gets heat and pressure first, and is subjected to it for a longer period than the top boards. The time necessary to close one opening in a standard press is equivalent roughly to the time required to close a multi-opening press simultaneously. A simultaneous closing press can be closed gradually to prevent blowing, yet have a fast overall closing time compared to the time required to completely close a standard multi-opening press.

Some particleboard manufacturers have indicated that, when using a regular multi-opening press, it becomes increasingly difficult to maintain constant tolerances, due to the allowances which must be made for the weight of the press itself.

Relatively new in the particleboard industry is the installation of a high frequency coil in front of a 1 to 4-opening main press. The output of such a plant is maintained by having a larger area press with a much faster press cycle. Lower temperatures in the main press mean lower operating costs, and high frequency heating increases the tensile strength of the board due to more consistent density (mentioned under Densification Pattern). The bond takes place at the centre of the board first and works to the outside. This type of heating is extremely important where a company is producing a high percentage of thick boards. Although the high frequency coil is expensive, the cost of the main press is considerably reduced. This system warrants consideration partic_ ularly where there is an abundance of inexpensive energy.

There are several variations in the method of laying down the chips on the mat--the most common being (i) one chip drop for a homogeneous board, (ii) several forming stations each laying down a single layer for multi-layer boards, and (iii) one forming station with an air or screening system for chip sorting in a graduated layer board. The forming station may be stationary, with the mat-laying equipment passing beneath it, or the forming station may move forward and backwards on a track laying down chips in one or two directions.

Some systems use cauls (metal plates on which the mat is formed) which may or may not pass through the main press. While most caul systems use only a bottom caul, one of the largest plants in the world uses both a top and bottom caul. Mats may be inserted into the main press by trays or belts in caulless systems. Some systems use a continuous metal belt, which passes through a single opening main press, or passes through a movable prepress and discharges the hardened mat at the entrance to the main press.

While some of the most modern installations in the world today use cauls, there is a definite trend towards a caulless system, and many engineering firms which utilized a system with cauls now offer a caulless system as well, or have gone over entirely to the latter. Some of the advantages of the caulless system are:

(i) better thickness tolerance

(ii) less sanding loss

(iii) better heat balance

(iv) shorter press cycle and consequently higher output

(v) economizing of construction parts and space

(vi) elimination of caul cooling and maintenance

(vii) better utilization of heat energy.

Some manufacturing processes are designed to operate at maximum efficiency on an output of 100 tons per day or more, so that anyone contemplating a 50-ton per day mill could safely disregard these systems. Conversely, some systems are designed for underdeveloped countries where the board quality requirements are low, and the output may only be 10 tons per day. It will be seen then that the size of a proposed plant will eliminate certain systems automatically. If a company has a low class waste problem, and is contemplating entering the particleboard field, it may not be practical to install expensive quality control equipment to try and compete for the quality market against companies which have first class raw material (roundwood) available. Rather, it would be advisable to look for the system which would produce the best marketable product with the raw material available. All systems have advantages and disadvantages so that, in essence, it amounts to a melding of a company's requirements with the most advantageous features of the various systems within certain output limits.

COMPETITIVE PRODUCTS

There are two products in Europe which compete directly with particleboard, and because of the raw materials, method of manufacture, and similarity of end product, they should be examined.

Mixolite

This process was developed in Austria and utilized fibrous waste material to produce a building board without the addition of resin. Boards can be produced from straight sawdust without the addition of a chemical binder. Although these boards do not have the strength properties of particleboards, they stand up better than particleboard for exterior use. Their main uses in Europe are exterior sidings, core stock, as a base for various plasters and stuccos, ceiling tiles, and partition walls. The process can be varied to produce boards of different properties for a wide range of applications. As a general rule, boards are produced in the middle density range, 30-39 lbs./cu.ft.

In the manufacture of mixolite boards, sawdust enters the plant by a conveyor and passes over a system of screens which separates fine and coarse material. The coarse material is diverted through a grinding machine which reduces the particles to the required size, and these particles are added to the regular flow. Water is added to this screened material, and the watery mass passes through the mixoliter machines, which refine the material to slime. This material then passes over fine screens which drain off the excess water before going to box cauls, where it is spread into mats. These mats are dewatered in a cold primary press and then stacked (up to 32 in a stack) and pressed in a large one-opening cold press. The pressed stacks are clamped and conveyed to the dry kilns where the internal bonding is achieved. The mats are still on their cauls which have metal collars attached. Depending on thickness and density the mats remain in the kilns up to 14 hours, and are then taken from the kilns, where the cauls are removed and the boards conveyed to the trim saws and sanding machines.

Flaxboard

For many years flax has been grown in Western Europe for the textile industries. The fibres alone were used for making cloth and the outer husks or shives were burned. In 1948 the Belgians developed a method for making boards from the shives. The shives, when delivered, contain various impurities which must be eliminated to ensure the homogeneity of the mass. Dust, which absorbs a great deal of resin and causes excessive wear on equipment, is removed by air. Flax roots must be eliminated, since they would cause unequal distribution of the material, as well as uneven surfaces on the finished board. Seeds are also removed, as they would attract rodents. The cleaned shives are then coated with resin, and the manufacturing process from here on is identical with that of particleboard.

The density range is from 18 lbs./cu. ft. to 44 lbs./cu.ft., although the bulk of the European production is in the 35-37 lbs./cu. ft. range. Flaxboard makes an ideal core stock for furniture, since it is stable, has a smooth surface and is generally more economical to use than particleboard. It is also used widely in Europe for shelving, built-in furniture, decorative wall and ceiling panels, wall partitions, subfloors, roof decking, roof and wall sheathing, heating and ventilating ducts, acoustic tiles and in prefabricated buildings. Most of the flax grown in North America places heavy emphasis on seeds, and this type of flax produces considerably less fibres and shives than the fibre flax grown in Europe. According to the Belgians, it is not economical to grow flax for the production of flax-board alone--it should be combined with a textile, pulp, or vegetable oil plant.

END USES

The furniture industry readily accepts particleboard as a replacement for core material, where it means a saving in costs, and where physical properties are adequate to meet its fabrication requirements. Particleboard really got its start in the furniture industry, and this is still the main market. However, new uses are growing rapidly, especially in areas such as Europe, where timber is scarce. The main potential for the future lies in the building industry, Europe being much more advanced in this area than is North America.

Particleboard is used widely for flooring in Europe, where it is laid on joists and covered with linoleum or tile. It has been estimated that flooring demands in Britain could utilize their total particleboard production. The United States industry has developed a flooring grade, but it is used mainly as an underlay for tile. Flooring grades are usually of a higher density, and manufactured to a densification pattern, which emphasizes resilience. The shortage of houses is general throughout Europe, and this shortage has been partially met by the development of industrialized housing. Particleboard is an ideal material for this purpose, and is used as wall sheathing, roof sheathing, partitions, cupboards, shelving, built-ins, and decorative wall and ceiling panelling. Particleboard in Europe is widely recognized by architects, and it is found in hotels, hospitals, restaurants, bars, schools, office buildings, apartments, libraries, bowling alleys, auditoriums and theatres, as flooring, wall, and ceiling coverings. Plastic faced particleboard is easy to clean, has a pleasant appearance, and meets the highest standards of hygiene. Prefabricated washroom cubicles for schools and commercial establishments are made of particleboard, with hardboard or melamine faces. Owing to hard-wearing qualities and ease of working, it is particularly suitable for built-in fitments, sliding doors, and furnishings of mobile homes, as well as partitions, doors, ceilings and bulkheads in the shipbuilding industry. It is ideally suited when faced with laminates as counter tops, decorative walls and displays in retail establishments. Faced with asbestos, it is used in heat ducts, giving considerably less heat loss than metal. It is used to line air ducts for tunnels in various parts of Europe. In several countries of Europe, where tile is used for roofs, particleboard roof decking has been covered with two layers of bituminous felt. The materials are all factory-made to a single module, reducing roof loading costs of material and labour, and giving improved insulation cutting down the weight of the roof by more than fifty per cent.

Particleboard has also been laid under tiles with a felt underlay. Some work is being done in Europe on the development of a phenol-bonded board for exterior sidings. This market is expected to grow. The insulating qualities of particleboard over brick, metal and mineral-based material, is a big selling point to Europeans.

American manufacturers on the West Coast are producing a high density particleboard as both strip and block flooring. This material is prefinished, and is reputed to be fifty per cent harder than oak flooring. An exterior phenol-bonded siding is also on the market in the United States. In all of these cases, particleboard meets certain laid down standards, enabling architects to specify this material with confidence.

Moulded Particleboard

Particleboard can be produced in moulded forms. A German company with licensees in various parts of the world, makes a wide range of consumer products, such as one-piece drawers, trays, stools, table tops, containers, cabinets, window sills, luggage, typewriter cases and wall tiles, as well as a variety of moulded components for the automobile and appliance trades. Decorative melamine laminates or wood veneers are bonded to the particleboard as an integral part of the moulding operation.

RESINS

Resins used as a binder in the manufacture of particleboard should satisfy most of the following requirements:

(i) Any resin used should have a low viscosity so that it can be sprayed on the fibrous material without the use of excessive air pressure.

(ii) It should have solid content of at least 50 per cent, to avoid adding an excessive quantity of water.

(iii) It should have a pot life at room temperature of several hours, to allow batches of binder to be prepared in reasonable quantities.

(iv) It should set in a reasonable time, at a reasonable temperature, to allow economic use of the hot press.

The most commonly used binder in the particleboard industry is urea formaldehyde, although the use of phenol formaldehyde is growing, due to its higher resistance to moisture and weathering. The use of a phenol formaldehyde, instead of a urea formaldehyde resin, can only be justified if it produces a better board with a wider field of application, or if it reduces the cost of the board either by its lower price or through other advantages during manufacture. As far as resin costs are concerned, phenol is more expensive than urea, but the spread has been narrowing in the past few years. The demand for phenolic-bonded boards will probably increase. It is useful then to consider the problems arising in their use - Phenol has a lower reactivity than urea, necessitating higher pressing temperatures and longer pressing cycles, thus slowing down production and reducing output. Unlike urea resins, little can be done to influence the setting speed of phenolic resins by the addition of hardeners. Moreover, the degree of setting required by phenolic resins appears to be greater than that of urea, necessitating a careful reduction of pressure, allowing excess steam to escape, thus avoiding blowing of the boards. On the other hand, phenolic manufactured boards may be stacked tightly immediately after pressing, as phenolic resins are not subject to hydrolysis. Melamine resins are more resistant to severe service than urea resins, but are more expensive than phenols. Their principal use is to fortify or improve the permanence of urea resins, and for use with decorative laminates. Resorcinol resins can be cured at lower temperature than phenols, standing up equally well, but are more expensive. Continuing research is striving to reduce the cost of phenols, melamines and resorcinol, by the addition of cresols, xylods, tannins and lignin derivatives, but apparently results so far have not been too successful.

Since particleboard is made from material containing cellulose, which is hygroscopic, the board swells when it picks up water. It is, therefore, desirable to impart water repellancy to the board, in order to decrease water absorption and consequent swelling. Wax emulsions are commonly used as sizing agents for this purpose. These wax emulsions may be pre-sprayed on the chips (before the resin), or they may be mixed with the binder, and the mixture sprayed on the chips. The amount of wax emulsion added is usually less than 1 per cent, but depends on the wood and its porosity, pH factor, amount and type of binder, press temperatures and pressures, humidity of the chips, and density of the finished board.

STANDARDS

Commercial standards are developed by the producer, distributor and consumer. They are used most effectively in conjunction with purchase orders and sales contracts. The purpose is to promote fair competition, to provide a basis of understanding between buyer and seller, to define quality levels for products in accordance with the principal demands of the trade, and to provide for close adherence to the qualities thus defined. They specify performance characteristics for moisture content, density, modulus of rupture, modulus of elasticity, internal bond, dimensional stability, and screw holding. They also include definitions of trade terminology, and a uniform method of certifying or labelling particleboard.

Germany was the first country to set up standards for particleboard (DIN 68671). However, most European countries now have their own standards. Britain uses "British Standard 2604-1963, Resin bonded wood chipboard" and British Standard 1811-1961, "Methods of Test for Wood Chipboards and other Particle-boards". The trade in the United States uses "Commercial Standard CS 236-61, Mat-Formed Wood Particleboard (Interior Use)", although this standard is being revised to include such things as accelerated aging, exterior uses, etc. Work is being carried out in Canada on proposed standards, but the only published specification is that of the Canadian Government Specifications Board for "Board; Particle Building Construction 11-GP-1", dated November 28, 1958.

TECHNICAL NOTES ON QUALITY CONTROL

Hydrolysis

When the pressed boards are removed from the hot press, a considerable amount of heat is retained within the boards. Storage in piles under such conditions may result in a degradation of the board qualities, essentially due to hydrolysis of the bonding resin. Delamination resistance is probably the property most affected. However, surface appearance may also be affected, along with a reduction in bending strength and stiffness. Boards in the centre of a pile would be affected most. Thus, it is clear that any method which reduces the stack temperature will result in less degradation.

Such reduction may be achieved by introducing a slight delay before stacking, or by cutting down the number of boards in a stack. Some plants pass the boards slowly through an air-cooled chamber. Moisture content of the boards plays a predominant role in hydrolysis. At low moisture content, say 4 per cent, there is very little hydrolysis, while at a moisture content of, say, 12 per cent the hydrolysis effect is severe. This points to the desirability of producing boards with as low a moisture content as is practicable. Hydrolysis is not a factor when phenol resins are used.

Board Conditioning

On removal from a hot press, particleboard is in a highly plastic condition, the wood being at a high temperature, with moisture content generally between 6 per cent and 10 per cent.

Under such conditions the board is very sensitive to any deforming tendencies. There is a high moisture content in the centre of the board, and a low moisture content in the outer faces. In reaching moisture equilibrium, the tendency is for the central core to shrink and the outer face to expand. The restraint of these shrinkages and expansions may result in internal stresses, the magnitude of which depends very much on board conditioning. Investigations have shown that when boards are cooled quickly, the stresses become locked in, so that boards are in a permanently stressed condition. When boards are allowed to cool slowly, the plasticity of the wood absorbs the stresses, and after conditioning, results in stressfree boards. In normal current production methods, the unequal moisture distribution is inevitable, though with high frequency heating a more even distribution could be expected. Lower press temperatures and lower moisture content both reduce the moisture content gradient, through the thickness of the board and, therefore, reduce the effect. But slower board cooling is likewise beneficial.

Densification Patterns

When a piece of particleboard of a given density is divided into several layers parallel with the plane of the board, and the density of each layer is determined, it is usually found that the density of separate layers is not equal. The change is, as a rule gradual, and follows a pattern known as the densification pattern. The significance of the most common and most useful densification pattern lies in the fact that the board, instead of being of homogeneous structure, becomes essentially a sandwich panel, where two strong and heavy sheets of material are kept attached to each other by a layer of comparatively weak and light material. This type of board possesses advantages as well as disadvantages. Among the advantages are high face density, high stiffness, high bending strength, high grade of surface texture, high resistance of faces to water absorption and swelling. The drawbacks are connected with low core density which causes low edge screwholding power, low delamination resistance, high water absorption and low shear value. In spite of the drawbacks, a manufacturer of boards of this type can produce from the same amount of raw material a board which is both stronger and stiffer than a board of the same weight but of different densification pattern. In addition, such a board has good firm surfaces. Realizing the effect of densification pattern on properties of the board, and knowing approximately the degree of this effect, the manufacturer can advantageously arrange for the densification pattern to be of the type giving him a board with the properties he most requires. The significance of the densification pattern is very great, since exactly the same quantity and quality of raw material can be converted into a high quality or low quality board. It rests with the manufacturer to choose from patterns available to him, the one that best suits the purpose in hand.

It is appropriate to examine the conditions which result in a densification pattern of one type or another. Without some core resistance, the faces cannot be compressed. The core is most resistant to compression when it is cold and comparatively dry. As soon as the press platen heat reaches it through the faces, and especially with moisture present, the core will become plastic, will gradually lose its resistance and start becoming compressed. It follows that, to achieve the most efficient face densification without unduly densifying the core, the latter should be kept cold and dry. In addition, the core is more resistant to compression when it consists of thick chips which are not so easily mouldable, even when in a hot and wet state. The main conditions favourable for achieving a high degree of face densification are (i) fine face chips, (ii) high face chips moisture content, (iii) coarse core chips, (iv) dry core chips, (v) high temperature of the press, (vi) high pressing pressure, and (vii) quick closing of the press.

For obtaining a board with comparatively low face density and high core density, conditions should be reversed thusly:
(i) coarse face chips, (ii) dry face chips, (iii) thin core chips, (iv) core chips of high moisture content, (v) low press temperature, (vi) low pressing pressure, and (vii) slow press closing.

A manufacturer very often produces a board with a poor densification pattern when a good mattress with wet fine face layers, and dry coarse core layer, is built up on a hot caul plate (which quickly dries the outer portion of the bottom layer), after which it is left for a time in the loader (where the upper outer layer begins to dry out), or is overexposed to the radiation and contact heat of the top platen of the hot press before the press is closed, and high pressure applied. In other words, a perfectly satisfactory material will result in an inferior board only because the conditions of treatment are faulty. Of course, all these conditions are applicable only within certain limits. For example, an unreasonable increase in the moisture content of chips will result in blistering. Similarly, lowering of the press temperature will eventually result in failure to produce a board.

It is readily apparent that a manufacturer producing a board for construction purposes (where bending strength is important), for flooring (where resilience is important), and for cabinet work (where edge screw holding ability is important) would necessarily attempt to attain entirely different densification patterns. The decision taken with regard to the densification pattern would likely be in the nature of a compromise.

PRODUCTION (Thousands of metric tons)

	1957	1959	1962	1963
World Production	800	1,400	2,786.0	3,394.0
Europe	465	845	1,888.0	2,316.0
Germany	234	365	672.6	731.2
Russia	N/A	52	223.1	279.8
United States	212	346	473.4	574.2
Canada	14	23	70.0	75.0 (est.)

Per Capita Consumption (Kilograms)

	1962 Kg.	1963 Kg.
Norway	13.7	17.5
Belgium	10.0	15.8
Switzerland	13.5	15.6
West Germany	13.1	14.0
Finland	9.8	11.1
Austria	9.9	10.3
Denmark	7.5	8.8
Sweden	7.1	8.1
Netherlands	7.5	6.6
France	4.5	5.8
Canada	3.8	3.9 (est.)
Italy	1.1	3.1
United Kingdom	2.5	2.6
United States	2.5	2.4
Portugal	1.1	1.3

There is a wide variation in the size of particleboard plants, ranging from an output of 10 tons per day, to 350/400 tons per day. The fifteen European countries belonging to the European Federation of Particleboard Manufacturers, have a combined total of 240 plants with the following capacity distribution:

Capacity (Cu. Metres)	Plants (1963)
up to 5,000 M^3	43
5 - 10,000 M^3	60
10 - 20,000 M^3	38
20 - 30,000 M^3	60
30 - 40,000 M^3	12
40 - 50,000 M^3	15
over 50,000 M^3	12
	240

The United States has 50 plants, ranging from small captive plants producing 10 tons per day, to large dual line plants producing over 200 tons per day. It is estimated that Russia has about 15 plants, but they are all quite large, some of them with a capacity of over 300 tons per day.

EXTERNAL TRADE

Exports

In August, 1963 the tariff schedule of the United States contained for the first time a specific enumeration of wood particleboard item 245.50 at a rate of duty of 12 percent. Prior to this time the treatment of particleboard had been confusing. Not having been specifically enumerated, its classification depended on size and end use with the result that the rates of duty varied over a wide range and practically no particleboard was exported prior to August, 1963.

Effective December 6, 1965 the rate of duty on Canadian particleboard is 20 percent under United States tariff item 245.50.

In 1965 Canada exported particleboard only to the United States although in 1964 small quantities were shipped to Britain, Trinidad and Puerto Rico.

Wood Building Boards NES (Class 33599)	- DBS65-004
1964	- $138,437
January, 1965 - June, 1965	- $195,689

Prior to 1964 the Dominion Bureau of Statistics listed particleboard under a general heading, Building Boards NES (Class 35779) and under this heading in 1963 the exports amounted to $98,380.

IMPORTS

Particleboard enters Canada under tariff item 50600-1. The British preferential duty is $17\frac{1}{2}$ percent less a discount of 10 percent (i.e. 1.75 percent). The most favoured nation duty is 20 percent.

In 1963 The Dominion Bureau of Statistics set up Class 4150 - Reconstituted Wood Board, and as of January, 1964 this has been changed to Class 33595 - Particleboard (reconstituted wood board).

The bulk of Canada's imports of particleboard comes from the United States, although starting in late 1964 board from Russia began coming into the country as well as small isolated shipments from South Africa, Surinam and Norway.

Reconstituted Wood Board (Class 4150) - DBS 65-007

1963 - $145,285

Particleboard - reconstitued wood board (Class 33595) - DBS 65-007

1964 - $205,362

Jan. 1965-June 1965 - $195,689

FUTURE OF THE INDUSTRY

Particleboard is the fastest growing segment of the wood products field and indications are that this trend will continue. The development of the particleboard industry has meant a radical change in the raw material base of the furniture industry, which is still the main market. Commercial manufacture of furniture is no longer a handicraft industry, but one with large operating units, with high output, turnover, and efficiency. This development has reduced the proportion of sawn wood in furniture, and the future of particleboard in this industry is assured.

The growth of factory construction, unit construction, components, etc. in the building industry, are developments which will favour the use of particleboard. Dry wall construction methods will favour panel materials at the expense of plaster and tiles.

The particleboard industry is highly responsive to changing requirements and new markets, and new market areas will be found for modified board products and processes. Particleboard is sold to industrial users in a manner which enables production facilities to respond more rapidly to changing customer requirements.

Particleboard plants may suffer competitively from the pulp and paper industry for both roundwood and wood residues, but because it can operate efficiently on a smaller scale than pulp and paper, it can tap unused sources of residues, or smaller amounts of roundwood, such as plantation thinnings.

The size of individual particleboard plants is growing, as is the productivity per worker. This growth in size will obviously lead to lower overhead costs. In addition, lower prices for resins will probably result from the expanding market for them.

Particleboard should be able to take advantage of the rapid technical progress made in the past few years, and should remain cheap in relation to sawn wood and other competing materials.

There is a trend, particularly in the United States, to fit products more exactly to specific end uses, notably by the application of finishes during manufacture.

According to the "European Timber Trends and Prospects", published by the Food and Agriculture Organization of the United Nations, the gross national product of Europe will probably double between 1960 and 1975. Thus, the total requirements of wood-based panel products is expected to treble in the same period. The greatest percentage increase is expected from particleboard. There is every reason to believe that the particleboard industry has yet to obtain the maximum benefits from the rapidly growing pool of technological developments and that considerable economies remain to be achieved.

There are very few countries in the world where the raw material necessary for entry into particleboard manufacture is not readily available. Heavy capital investment is not a requisite, and it is common experience that a locally made board may be counted on to find a market.

CONCLUSIONS

1. The particleboard industry will not be in any position to realize its potential in Canada until standards are established, for architects may not specify particleboard, and builders are wary of using it. The consuming public knows very little about it.

2. Advertising on an industry-wide basis must first explain to people that particleboard is a specific product, with specific qualities, that make it superior to other materials for certain uses.

3. Although the industry in Canada is not presently operating at capacity, there is a demand for low pressure laminates on particleboard, edge banding of particleboard with lumber, moulded particleboard and prefinished specialty items such as flooring and siding.

4. There is a trend in other countries for particleboard manufacturers to control prefabricated housing companies, and mobile home companies, as outlets for their production. The Canadian prefabricated housing industry has just formed a national association in an attempt to capture a larger share of the housing market. It would appear to be an opportune time for the particleboard industry to explore the possibilities of particleboard in prefabricated building, since panels are so well suited to this type of construction.

5. The last few years have seen a multitude of new type boards developed in Europe—sawdust, excelsior and cement, shavings and cement, sulphite waste, etc. These boards are sold in Europe, but what may be economically feasible in timber deficit areas may not be practical in Canada, where we have an abundance of wood resources.

Some of these products found markets in heavily populated European countries in the post-war period, whereas in Canada our building codes would not allow their use. A Canadian company faces few problems in order to commence the manufacture of these products, but some prior market research is essential. For instance, a small Canadian company may become a licensee for a product which is too specialized for the limited Canadian market because the break-even point is higher than the actual size of the market.

6. The Canadian particleboard industry is less sophisticated than that of Europe. Our existing market is less demanding, but as the industry expands, more quality control will be demanded, in line with specific standards and the addition of specialized products. Periodic technical trade missions to such countries as Britain and Germany would benefit the industry by keeping abreast of new developments in this fast changing field.

7. Any Canadian company contemplating entering the particleboard field would do well to examine trends in the medium density hardboard field which will soon be competing with particleboard for certain markets.

8. The industry in Europe has formed the European Federation of Particleboard Manufacturers' Association. This group's primary aims are to seek solutions to problems both economic and technical, to promote increased consumption of particleboard, and to present and support, before international organizations, the resolutions adopted by the countries represented. Periodically, the various working committees issue reports and bulletins to their members. Amongst the most active, is the Technical Committee, which seeks to improve the technology of the industry. The Canadian Particle-

board Association is eligible to become an associate member of this group, and might well consider such a step.

9. In Canada there is a need for end use studies in this field.

10. The rapid expansion of the plywood industry in North America during the past few years has, by its volume penetration, limited the use of particleboard in general construction, but as research continues, it becomes apparent that the main potential for the future of particleboard lies within the framework of the building industry.

Technological Data

Strength and Physical Properties of Flat-Platen Pressed Particle Board

USES AND APPLICATIONS:			FURNITURE					
			INSULATION				DECORATION	
Property	Value Metric	Value English	Light Density Metric	Light Density English	Medium Density Metric	Medium Density English	Heavy Density Metric	Heavy Density English
Density	g/cm³	lb/cu. ft.	0,3–0,5	19–31	0,5–0,75	31–47	0,75–1,0	47–62
Tolerance in Thickness	mm	inch	± 0,3	0,01	± 0,3	0,01	± 0,3	0,01
Tolerance in Length and Width	mm	inch	± 5,0	11/64	± 5,0	11/64	± 5,0	11/64
Modulus of Rupture	kg/cm²	p.s.i.	60–150	850–2150	120–250	1700–3500	200–350	2850–5000
Tensile Strength (Vertical to Surface)	kg/cm²	p.s.i.	1,0–3,0	14–42	3,0–8,0	42–115	0,0–12,0	115–170
Screw Holding (German Test Method)	kg	lb	30–80	66–176	00–110	176–242	110–160	176–352
Nail Holding (German Test Method)	kg	lb	8–15	17–33	15–25	33–55	25–30	55–66
Swelling in Thickness	%	%	2–5	2–5	5–10	5–10	10–15	10–15
Swelling in Length and Width (24-hr. immersion)	%	%	0,3	0,3	0,3	0,3	0,3	0,3

Conversion Factors

Square and Cubic Measures

144 sq. in.	=	1	sq. ft.
9 sq. ft.	=	1	sq. yd.
30 1/4 sq. yds.	=	1	sq. rod
160 sq. rods	=	1	acre
640 acre	=	1	sq. mile
4,840 sq. yds.	=	1	acre
1,728 cu. in.	=	1	cu. ft.
27 cu. ft.	=	1	cu. yd.
128 cu. ft.	=	1	cord
1,000 board ft.	=	2,36	m³

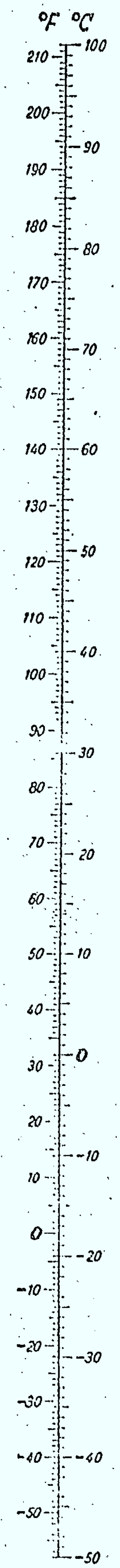
Particle Board
(3/4" thick / density 0,625 gr/cm³)

1 cu. metre	=	566	sq. ft.
	=	0,625	ton (met.)
1 ton (met.)	=	1,6	cu. metres
	=	906	sq. ft.
1000 sq. ft.	=	1,767	cu. metres
	=	1,161	ton (met.)
1 gr/cm³	=	62,4283	lb/cu.ft.

Standard Units

	English/Metric				Metric/English			
Length	1 inch	=	25,4	millimetres	1 millimetre	=	0,039	inch
		=	2,54	centimetres		=	0,003	foot
		=	0,025	metres	1 centimetre	=	0,394	inch
	1 foot	=	304,8	millimetres		=	0,033	foot
		=	30,48	centimetres	1 metre	=	39,379	inches
		=	0,305	metres		=	3,281	feet
	1 yard = 3 feet = 36 inches	=	0,914	metres		=	1,094	yards
	1 mile = 1,760 yds.	=	1,6	km	1 km	=	0,621	mile
Area	1 sq. in.	=	6,452	sq. cm.	1 sq. cm.	=	0,155	sq. in.
	1 sq. ft. = 144 sq. in.	=	0,093	sq. m.	1 sq. m.	=	10,764	sq. ft.
	1 sq. yd. = 9 sq. ft.	=	0,836	sq. m.		=	1,196	sq. yds.
	1 acre	=	0,405	hectare	1 hectare	=	2,471	acres
	1 sq. mile = 640 acres	=	2,59	sq. km.	1 sq. km.	=	0,386	sq. mile
Volume	1 cu. in.	=	16,387	cu. cm.	1 cu. cm	=	0,061	cu. in.
	1 cu. ft. = 1,728 cu. in.	=	0,028	cu. metre	1 cu. metre	=	35,314	cu. ft.
	1 cu. yd. = 27 cu. ft.	=	0,765	cu. metre	1 cu. metre	=	1,308	cu. yd.
	1 Imp. gallon	=	4,546	liters	1 cu. metre	=	1000	liters
	1 US gallon	=	3,785	liters	1 liter	=	1,756	pints
	1 barrel (Oil) = 42 US gallon	=	158,76	liters				
Weight	1 lb.	=	0,454	kg.	1 kg.	=	2,205	lb.
	1 ton (sht) (U.S.)	=	907,18	kg.	1 kg.	=	0,001	ton (sht)
	1 ton (sht) (U.S.)	=	0,907	ton (metric)	1 ton (metric)	=	1,102	tons (sht)
	1 US-hundredweight	=	45,359	kg.				
	1 ton (lg) (engl.)	=	1,016	ton (metric)		=	0,984	ton (lg)
	1 ton (lg) (engl.)	=	1016	kg.				
	1 engl. hundredweight (cwt)	=	50,800	kg.				
	1 oz.	=	28,350	gram	1 gram	=	0,035	oz.
	1 Pud (russ.)	=	16,380	kg.				
Density	1 lb./cu. ft.	=	16,02	kg/m³	1 kg/m³	=	0,062	lb./cu. ft.
Pressure	1 lb. per sq. ft.	=	4,882	kg per cm²	1 kg per cm²	=	0,205	lb. per sq. ft.
	1 lb. per sq. in.	=	0,07	kg per cm²		=	14,22	lb. per sq. in.
		=	70,31	gr per cm²	1 gr per cm²	=	0,014	lb. per sq. in.

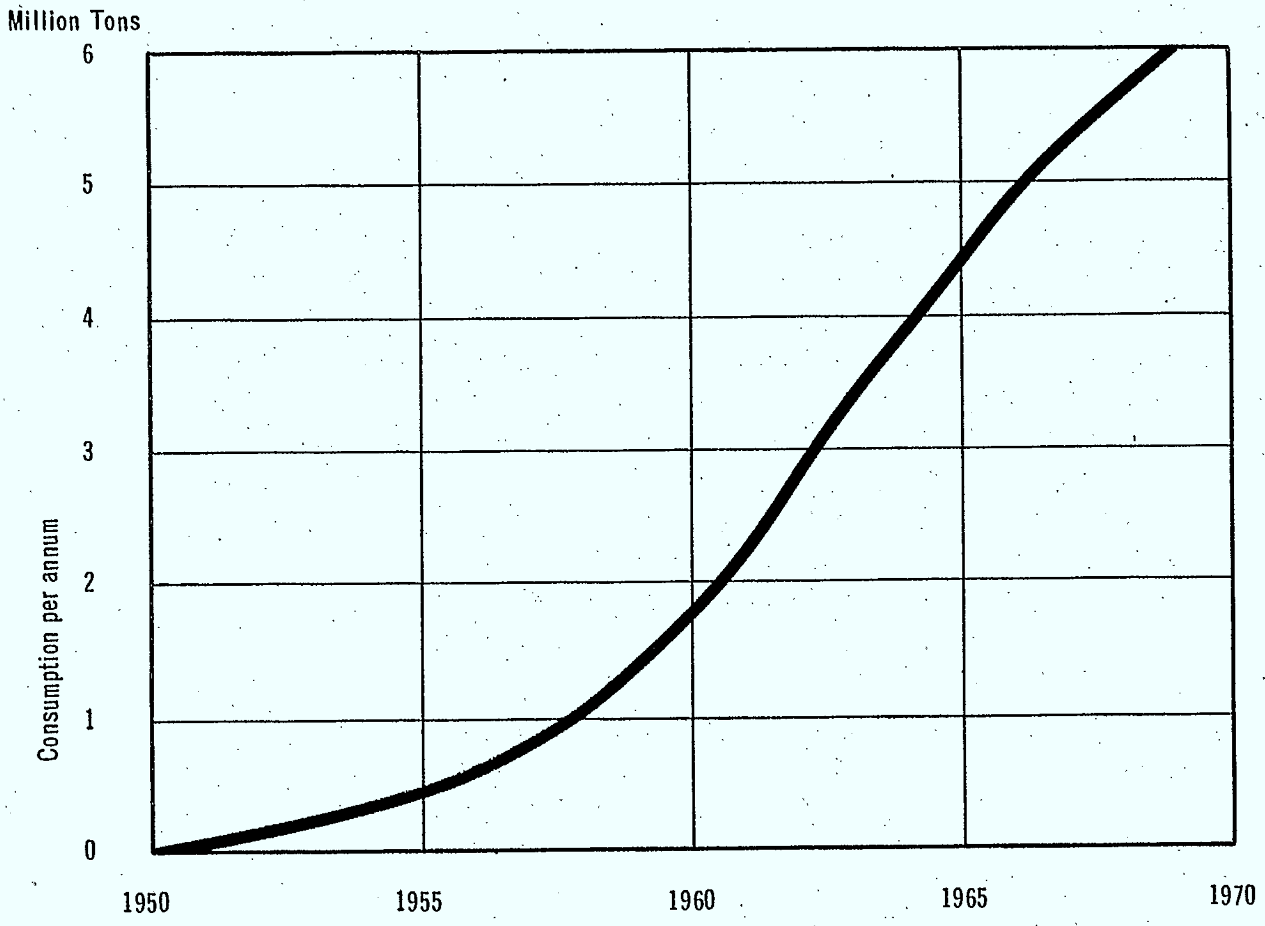
Temperatures



Formulae:

°C = 0.555 × (°F — 32) ⊙ °F = 1.8 × °C + 32 ⊙ n°C = 32 + 9/5 n°F ⊙ n°F = 5/9 (n — 32) °C

WORLD CONSUMPTION OF WOOD PARTICLE BOARDS



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3. Manufacturing Processes - excerpts from articles appearing in Board Magazine."