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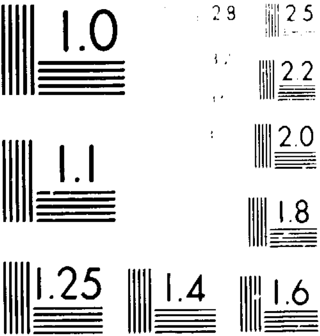

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RECENT DEVELOPMENTS IN PARTICLE BOARD PRODUCTION *

by

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INTRODUCTION

In order to appreciate the recent developments in particle board production, it might be interesting to know the reason for producing particle board.

In Europe, the reason is mainly economical, because the yield of useable volume is only one half or less of roundwood volume produced.

The solid wood is too expensive, because the volume needed is at least double the volume produced. Furthermore, manpower is very expensive.

Particle board therefore represents:
- a cheap raw material for furniture;
- smooth surface, easy to finish;
- a raw material permitting the mechanization of furniture production, with unskilled manpower;
- the possibility of making a good product with hitherto unused low grade woods.

With the development of water resistant glues, particle board became a building material appreciated for inside walls, roofs, ceilings and sub-floors. Very easy and cheap to use, particle board decreases the cost of houses. Its introduction however necessitated the development of new building techniques.

In the United States of America, where lumber and plywood are cheaper, particle board is still considered a "new product".

In this case, particle board, with costs quite similar or only a little cheaper than other wood products, must show technical advantages for a specific use: smooth and hard surfaces: thickness regularity and so on.

The purpose is to make a product which can compete with plywood, not specially on the raw cost, but on the quality and on the use economy (large surface; easier and cheaper to finish, etc...).

In the developing countries, the purpose is to obtain good and cheap raw materials for furniture and buildings, and at the same time, to promote industrial development.

Each particular situation must be analysed before selecting a technological process to be introduced.

For these reasons, instead of describing completely the new process machinery, it was deemed preferable to try to show the evolution of the technology.

The following points will be considered:

I. Possibilities of the general process of board manufacture.

II. Some raw material effects on board properties.

III. Evolution of board manufacture.

IV. Structural board technology and uses.

V. Cement board technology and uses.

VI. Economical considerations.

VII. Conclusions

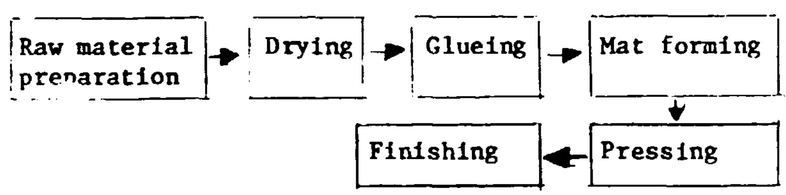
I. POSSIBILITIES OF THE GENERAL PROCESS OF BOARD MANUFACTURE

The particle boards (standard board, building board, thin board, structural board, cement bonded board etc.) are a large family of products submitted to a perpetual technological evolution.

The market needs products with well-adapted properties at lower costs. The purpose of the technology is to adapt the process to the needs in relation with the availability of raw materials.

The fantastic development of wood-based panels during the last twenty years, everywhere in the world, was achieved both because of the quality of the products and by the flexibility of the general process. The recent evolution of the particle board production is more a better application of the fundamental principles than a real new basic technology.

The main stages of the general process can be summarized as follows:



Each stage has a certain capacity of evolution, in relation with the raw material availability, the market needs and the technological level of the country.

1. Raw material preparation:

Due to the flexibility of the technology, a wide range of raw materials can be used in the production of boards. The choice depends on the local conditions, but it affects the board's properties.

The nature of the raw material is more and more diversified. Initially only some wood species or agriculture residues were used: the recent evolution tries to use all kinds of raw materials to make specific end-use boards. For instance the typical board for furniture and non-load-bearing dry use calls for a mixture of wood and bark or wood and agriculture residues (flax for instance).

The important point is to decrease the cost of the board and for that reason use low cost raw materials. The quality of the board is especially appreciated for its surface properties. The competition for raw material requires the use of unfavourable forest products, like biomass.

The characteristics of the lignocellulosic material can be very important. The use of high density wood requires the increase of board density. To reach the quality of other wood panels, like plywood, the wood species have to be drastically selected to have low density and high compression strength. The availability of this kind of wood allows the development of structural boards or particular insulating boards (similar to those obtained using flax, sugar cane bagasse, etc.). The development of board with hydraulic bonding (with cement) requires raw materials free of excess extracts.

The particles made from the raw materials can correct or increase its inherent unfavourable characteristics. The machinery to make particles is not able to make only 100 percent of the exactly required particles. The yield of the machinery is largely depending on the form and the moisture content of the raw material. It is necessary to screen the particles. The severity of the treatment improves the quality but affects the economy.

So, the care taken in the preparation of particles is very important for each type of process. With the same machinery, the board can have very different properties according to the preparation used: knives of the cutters, severity of the screening, selection of the raw materials. For instance, structural boards and MDF require essentially the optimization of these parameters.

The drying of the particles and its level can be achieved by direct heating by gas at high temperature or indirectly. In the first case, used in typical particle board manufacture, the particles become brittle and the granulometry changes.

2. Glueing:

The glueing is one of the main parameters of the fabrication because the glue must provide the board's cohesion and other properties. From the typical urea formaldehyde glue, some boards are developed to be competitive with other building materials. The phenol and the melamine glues are largely developed because of their very good resistance to humidity. More recently, a very high moisture resistance glue has been developed: the isocyanate glue.

The glue ratio depends on the type of glue and the board properties required.

The glue form can help the technologist in special cases where the glue water content is undesirable, especially when the densification ratio is very high, to prevent blowing, as for the structural boards.

The quality or the fundamental properties of glue can be changed by chemical additives to adapt the curing very closely to the manufacturing process. Some particular properties of the board can be researched for special uses: protection against insects and fungi or to obtain a fire resistant board. Beside thermosetting glue, hydraulic bonding of the lignocellulosic raw materials can also be used. The main products used are cement, magnesite, gypsum or lime.

In this case too, the kind of mineral binder, the bonding ratio and the additives develop a family of products.

3. Forming mat:

The structure of the mat is one of the possibilities to change the properties of the board obtained from any given raw material. The following figure 1 shows the main types of boards: homogeneous, three or five layers, and graduated where, by a single operation, the finest particles constitute the surface and the biggest the core of the mat. Extruded boards also exist, but they are not common:

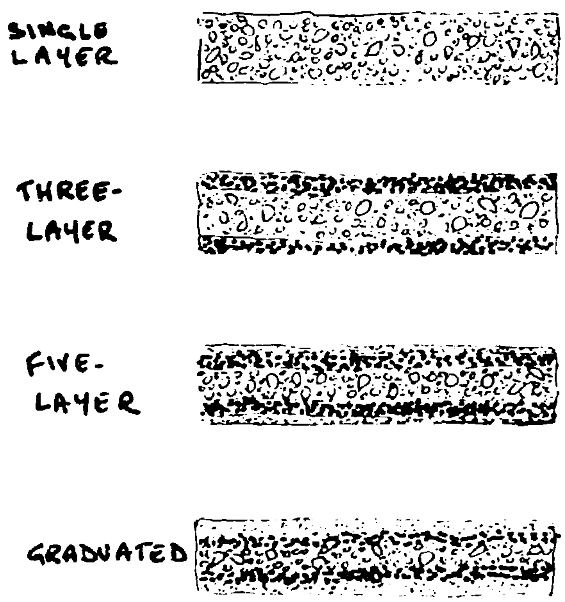


Fig. 1 Various types of mat construction.

When the layers or the fractions (fine, coarse) are prepared separately, it is possible to change the glue ratio, the type of additives to the glue and the humidity to obtain different technological effects (higher rigidity, smoothness of surfaces, etc.).

It is possible to minimize the effect of unfavourable raw materials (like bark, biomass, etc.) or of undesirable colour (dark coloured wood) by introducing it exclusively in the mat's core.

Beside these technical systems, new processes for the orientation of particles have been developed to increase the strength of the board in one direction (structural board). Mineral bonding offers other possibilities by the inclusion of solid wood pieces or insulating materials in the core of the board. It is possible because of the low pressure used (low density cement board) and the use of a cold setting binder.

For all processes, the main quality of the formation is the uniformity which determines the homogeneity of the board's property. For example, MDF could not have developed without the extreme precision of its conformation.

4. Pressing:

The pressing can have two effects: reduce the thickness of the mat to the required value and cure the thermosetting glue. The temperature, the time, the closing time and the pressure level are the main technological parameters affecting the baord's properties. Interaction with the glue system and the mat moisture content must be taken into consideration.

The mechanical process of the pressing especially affects the economy, but also has indirect effects on board properties (thickness uniformity, density profile, etc.) The typical process single opening and multi-opening press have long been the sole types used, but more recently the continuous process with the calender system especially adapted for thin board production has been developed. A very new system, operating on an industrial scale, runs with another principle, and is suitable to produce all kinds of boards.

The main advantage of the conitnuous system is the regularity of the pressing and the saving of time lost in closing, opening and loading of the conventional press.

The regularity of the pressure on the mat, the characteristics of the pressing and the quality of the press determine the thickness uniformity.

Conclusions:

This brief survey of the principles of board manufacture illustrates that the new developments in this branch of the wood industry are derived from the evolution of one or two stages of the manufacturing process.

Figure 2, on page 9, summarizes the main evolution.

It is very important to remember some technological laws which explain the evolution and at the same time, determine the limits of the new processes.

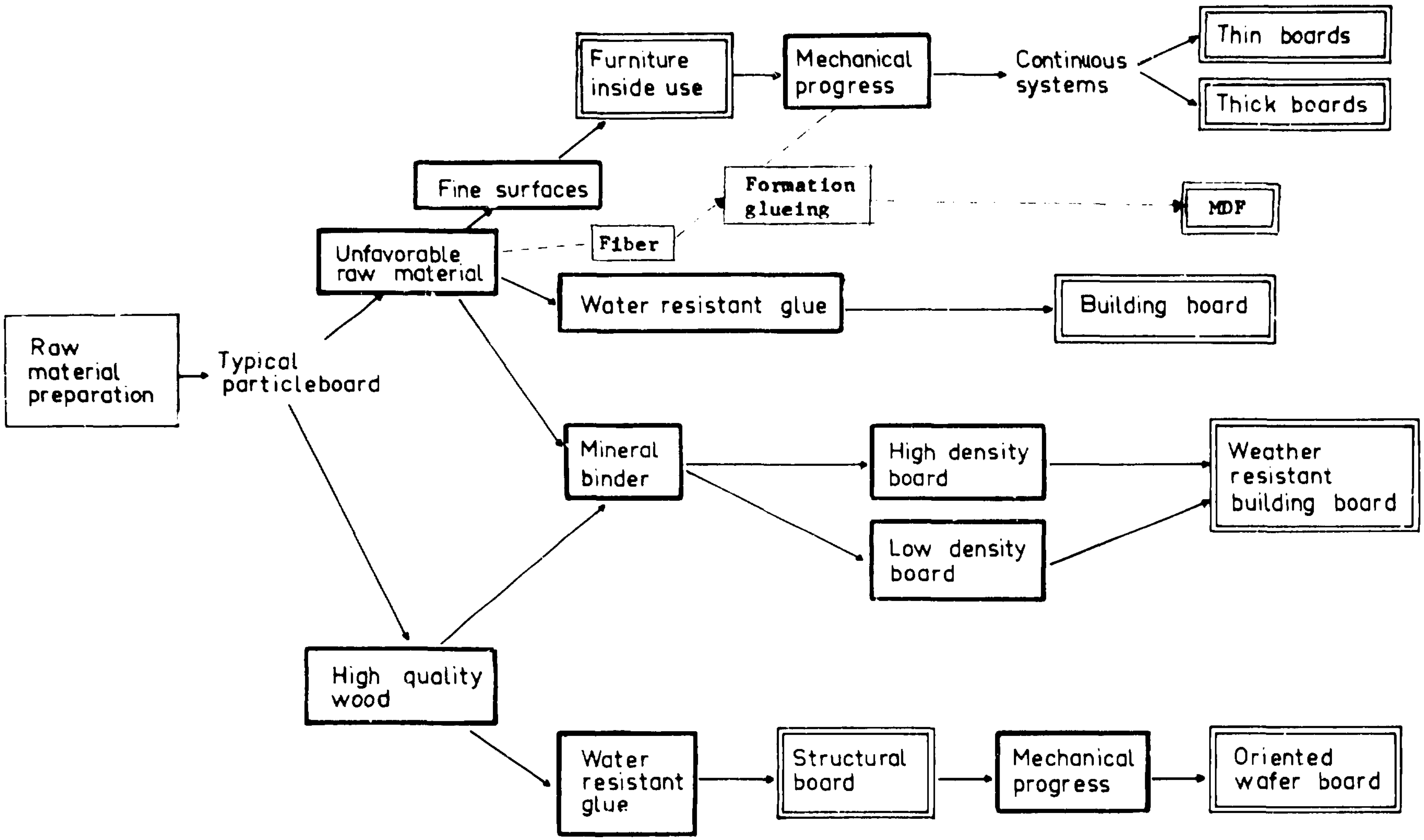


Fig. 2: Main evolution in the recent developments in particle board production

II. SOME FUNDAMENTAL PRINCIPLES AFFECTING BOARD PROPERTIES:

Some of the raw material parameters affect the board properties and are very important for the interpretation of the board technology evolution, in relation with the availability of the raw materials.

1. Effect of wood density:

The board density can be chosen without consideration of the raw material density.

Figure 3 shows the interaction between static bending strength and specific gravity. It appears that the bending strength is largely affected, at the same board density, by the raw material's specific gravity. However, the relationship between the two parameters is not proportional and depends on the resistance to compression.

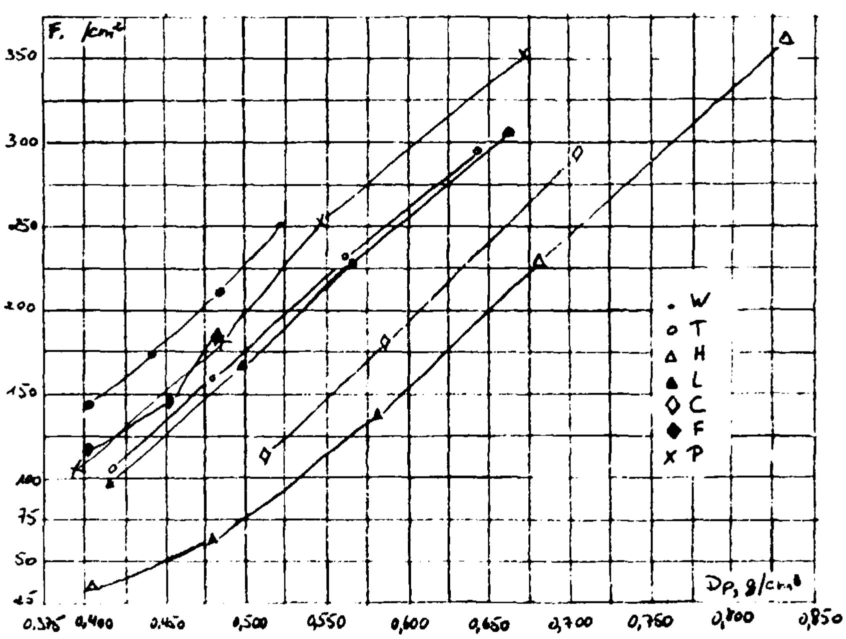


Figure 3

Relation between bending strength F and specific gravity Dp of particle board manufactured from different tree species.

LEGEND:
- W = Wawa (Triplochiton scleroxylon)
- T = Tola (Gossweilerodendron balsami ferum)
- H = Beech (Fagus silvitica)
- L.= Limba (Terminalia superba)
- C = Oak (Quercus spp)
- F = Fuma (Triplochiton spp)
- P = Poplar (Populus spp)

The relation between the densification ratio ($K = \frac{\text{Board Density}}{\text{Wood Density}}$), the wood specific gravity and the bending strength of the board is shown in Figure 4. The dark line represents the densification ratio, needed to have a determined bending strength. It shows that low density wood species need higher densification ratios than heavy wood species. So, to reach 250 kg/cm^2 in bending strength, a K ratio of about 1,8 for a low density wood species (0.3) and about 0,9 for a high density wood species (0,8) is needed.

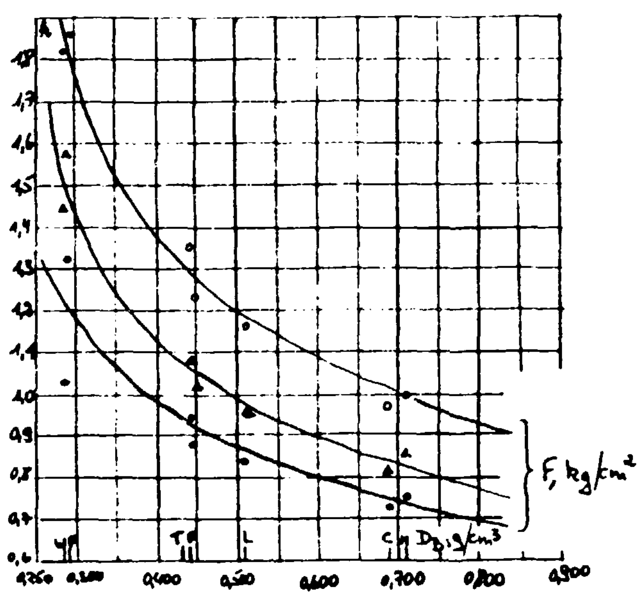


Fig. 4: Relation between densification ratio k, wood specific gravity D_B and bending strength F of boards.

That can be explained by the resistance to compression of the particles. Indeed, in order to reach the same mat densification, in the same conditions (humidity, particle shape, pressure speed application, etc.) it is necessary to develop variable pressures, according to figure 5.

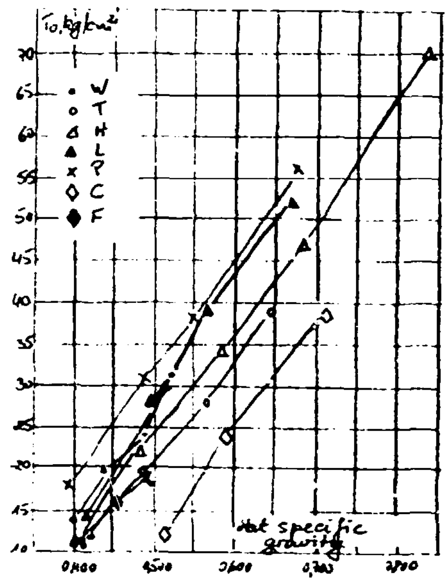


Fig. 5: Compression resistance To as a function of mat specific gravity (D_{mat}).
(For identification of species see fig. 3)

The pressure at the glue line is higher for the wood species showing a great compression strength. Consequently, the bending strength and the other board properties depend, for the same particle shape, on a parameter including wood density and densification ratio. This principle is applied in structural boards, aspen being one of the best wood species from this point of view. (See figure 6).

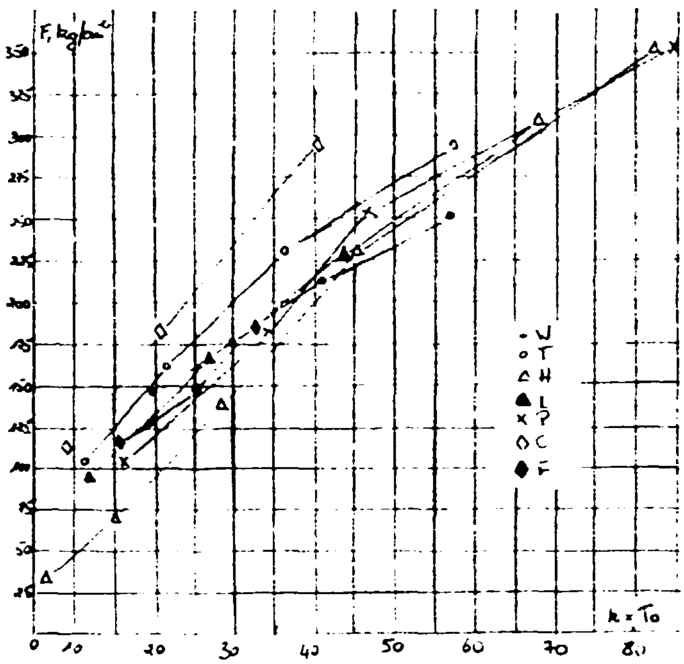


Fig. 6: Bending strength F as a function of k x To.
(For identification of species see fig. 3)

2. Effect of particle shape:

The shape of the particles affects the distri[illegible] of the density in the board's plan and through this effect, [illegible]fluences its properties (Fig. 7). If a board is cut into small pieces (for instance 1 x 1 cm x board thickness), the density distribution of these square specimens is affected by the particle shape, as follows:

- the thickness of the particle increases the density distribution;
- the length and the width have a smaller effect;
- the more homogeneous the board is (smaller density variations), the more the particle board ressembles MDF.

So, the particle's shape affects the uniformity of the density and consequently the local pressure.

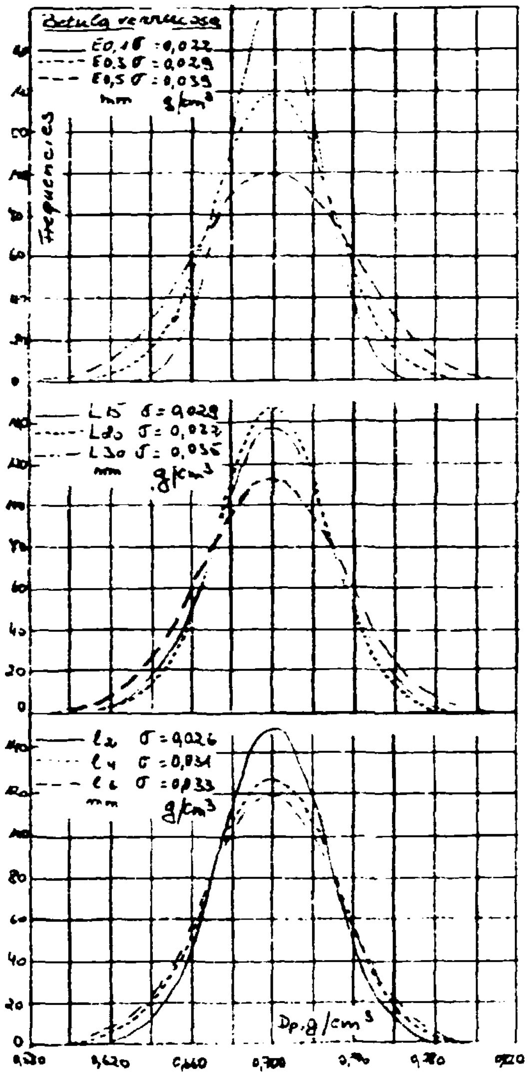


Fig. 7: Frequency of specific gravity of elements of 1 x 1 cm as a function of particle shape. Wood species: Betula verrucosa. Particle thickness 0,1 - 0,3 - 0,5 mm.

Under these conditions, the mat compression strength is dependant on the particle shape, as shown in figure 8.

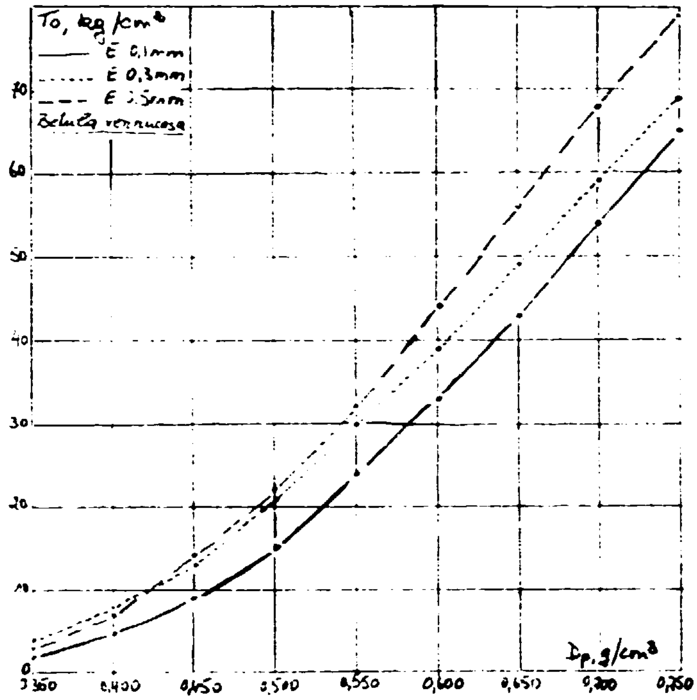


Fig. 8: Pressure To required to compress the flake mat to desired board specific gravity D_p. Wood species: Betula verrucosa; particle thickness: 0,1 - 0,3 - 0,5 mm.

In conclusion, the density of the wood species, its specific compressive strength and particle shape are the main raw material parameters which affect the board's properties. Structural boards are an example of the strict application of these principles.

3. <u>Raw material mixing</u>:

Particle board can be considered a mixing of many different particle shapes. Indeed, the machinery used is unable to cut the raw material to exactly the same size.

The dispersion of the length, width and thickness of the particles is dependant on the machinery used to cut the wood, the knife quality, the wood form and its moisture, etc.

The particle shape dispersion is reduced through a screening of more or lesser severity, but under normal conditions this dispersion remains important. Beside this first type of misture of raw materials, there can exist a larger number of possible mixtures according to local conditions:

- wood and bark. The latter can result from the use of unbarked (or partly barked) wood or through a supplementary bark addition;
- different wood species;
- wood species and agricultural residues (eg. flax) or other ligno-cellulosic materials;
- whole-tree particles. It is a new form of raw material produced by the chipping of the entire trees (branches, bark, wood, needles, etc.).

These raw materials do not have the same properties and give rise to boards of very different quality.

Figure 9 shows the evolution of the board's bending strength with the board density and the type of raw material.

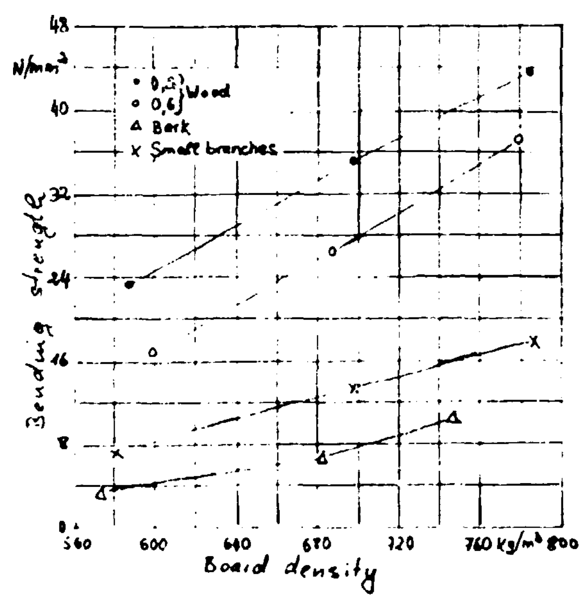


Fig. 9: Bending strength as a function of raw material and board density.

The differences are very large both for the mechanical as well as for the physical properties.

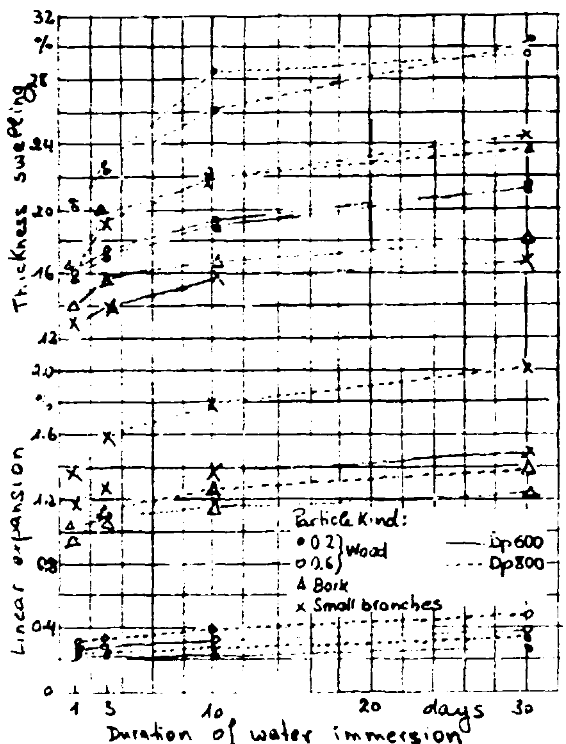


Fig. 10: Thickness swelling and linear expansion during thirty days of water immersion as a function of board density and raw material. Size of test specimens 20 x 5 cm - Density 600 kg/m^3, density 800 kg/m^3. Each value is the average of 60 specimens.

The mixing can be made in homogeneous boards, as shown in figure 11:

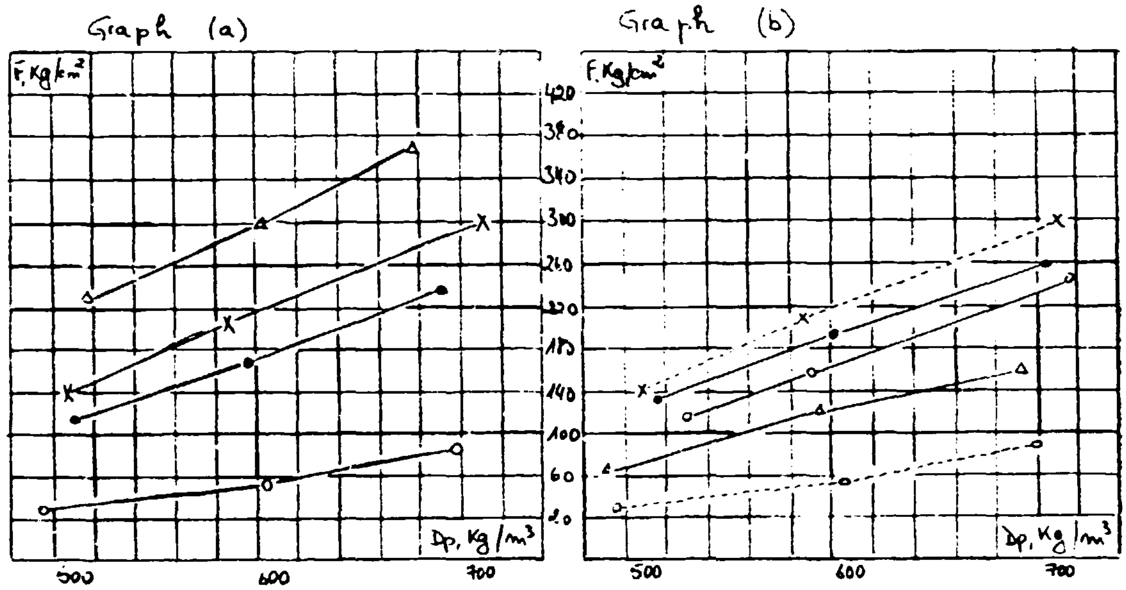


Fig. 11: Evolution of state bending resistance (F) in function of panel density (D_p) and type of ligno-cellulosic material used in (a) pure homogeneous boards and (b) mixed homogeneous boards.

Legend, graph (a)

- △ Very good particles, 0,2 mm thick
- X wood chips
- ● whole tree chips
- o small branches

Legend, graph (b)

Mixtures of wood chips and small branches:

- • - 10% branches
- O - 20% branches
- Δ - 50% branches
- x- - - -x 100 % wood chips
- o- - - - -o100% branches

It appears that the properties of the mixed board lie between the properties of the components. The relation which is mathematical is given by the following formula:

$$C = C_1X_1 + C_2X_2 + \ldots + C_nX_n$$

where:

C = characteristics of the mixed board (bending strength, etc.)

$C_1, \ldots, C_n$ = the same characteristics of board made under the same conditions, exclusively with the component 1, ..., n.

$X_1, \ldots, X_n$ = percentage of the component in the dry particle mixing.

The application of the formula gives very good estimated results (see fig. 12) and is applicable to all kinds of mixtures:

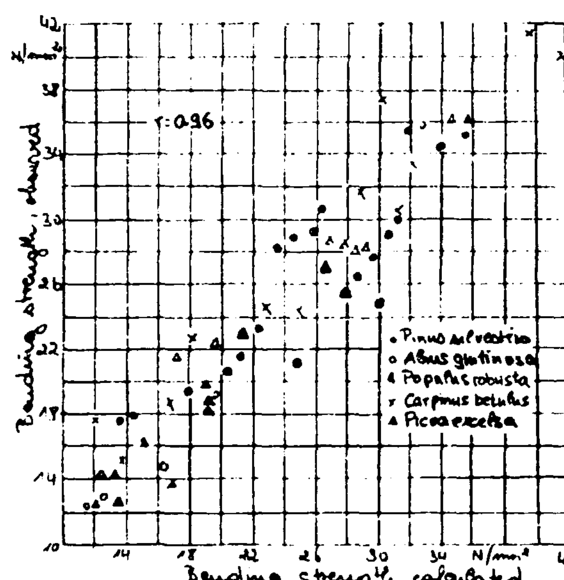


Fig. 12: Influence of small branch and bark percentage on bending strength. Relation between observed and calculated values according to the equation above. Each point represents the average of 3 board repetitions. This regression concerns the 3 board density levels (from 465 to 850 kg/m^3) and mixtures of particles from small branches and bark.

This point is very important and explains the carefulness of the preparation of particles in some new processes like structural board.

Indeed, using unbarked wood means that the board contains about 10 percent of bark particles. If the wood particles are of the first quality type, the effect for a board of 650 kg/m^3 can be calculated as follows:

Bending strength: - board without bark = 360 kg/cm^2
- board with only bark = 80 kg/cm^2
- mixed board (10% bark) =
$(0,90 \times 360) + (0,1 \times 80) = 332\ kg/cm^2$

To this quantity of bark, must be added a part of unfavourable wood particles (dust, fines, etc.) and by the same calculation we observe a practical bending strength quite lower than the board made exclusively with good particles.

This principle is exactly the thesis on which structural board was developed and can be applied to all kinds of boards including cement bonded boards.

III. BOARD MANUFACTURE EVOLUTION:

The manufacture of boards is really squeezed between two opposite obligations:

- to make a board of always higher quality and well adapted to the end use;
- to use more and more unfavourable wood because of the raw material competition and to reduce sosts.

One of the main uses of the board is furniture. For this industry, the first property required is the surface quality allowing a lower cost and an easier surface finishing. A first stage of the board evolution has been to make very fine surfaces, by a three-layer or a graduated system. To preserve the mechanical properties, the board density increases because heavier wood species are used.

Under the pressure of competition, production tends to increase with a decrease in the pressing time, an increase in the speed of the loading and also tends to be specialized to only one kind of board.

A. Manufacture of thin board:

The manufacture of thin board is particular by the fact that the pressure time, proportional to the thickness, is very short. So, the time to open and close the press becomes very important with regard to the total pressing time.

Two solutions are given to this problem:

1.1 Flat-pressing method:

This system uses a multi-opening press, with very fast opening. The mat is formed on textile cauls which are also used as press cauls.

The specific pressure is about 50 kg/cm^2. The quality of the machinery must be high, especially with respect to thickness uniformity to minimize sanding.

The pressing time used is about: 1,20 min for 4 mm.
1,34 min for 6 mm.
1,80 min for 8 mm.

The board density can reach 900 kg/m^3.

1.2 Continuous system (Mende process):

The continuous system consists in pressing the mat on a heated cylinder. Figure 13 shows the principle of the machinery:

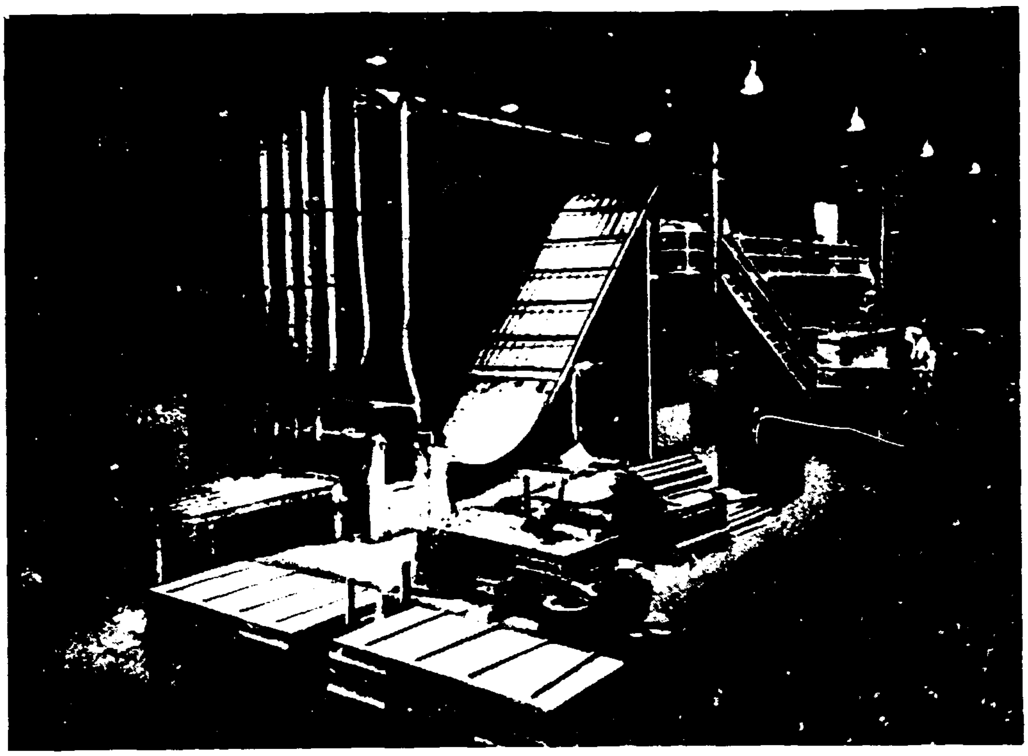


Fig. 13: The components of the Mende process continuous particle board system from dryer exit to dimension saws

The mat is formed on a continuous belt, with a graduated system (fig. 14). After its forming, it is immediately pressed by the cylinder (fig. 15).

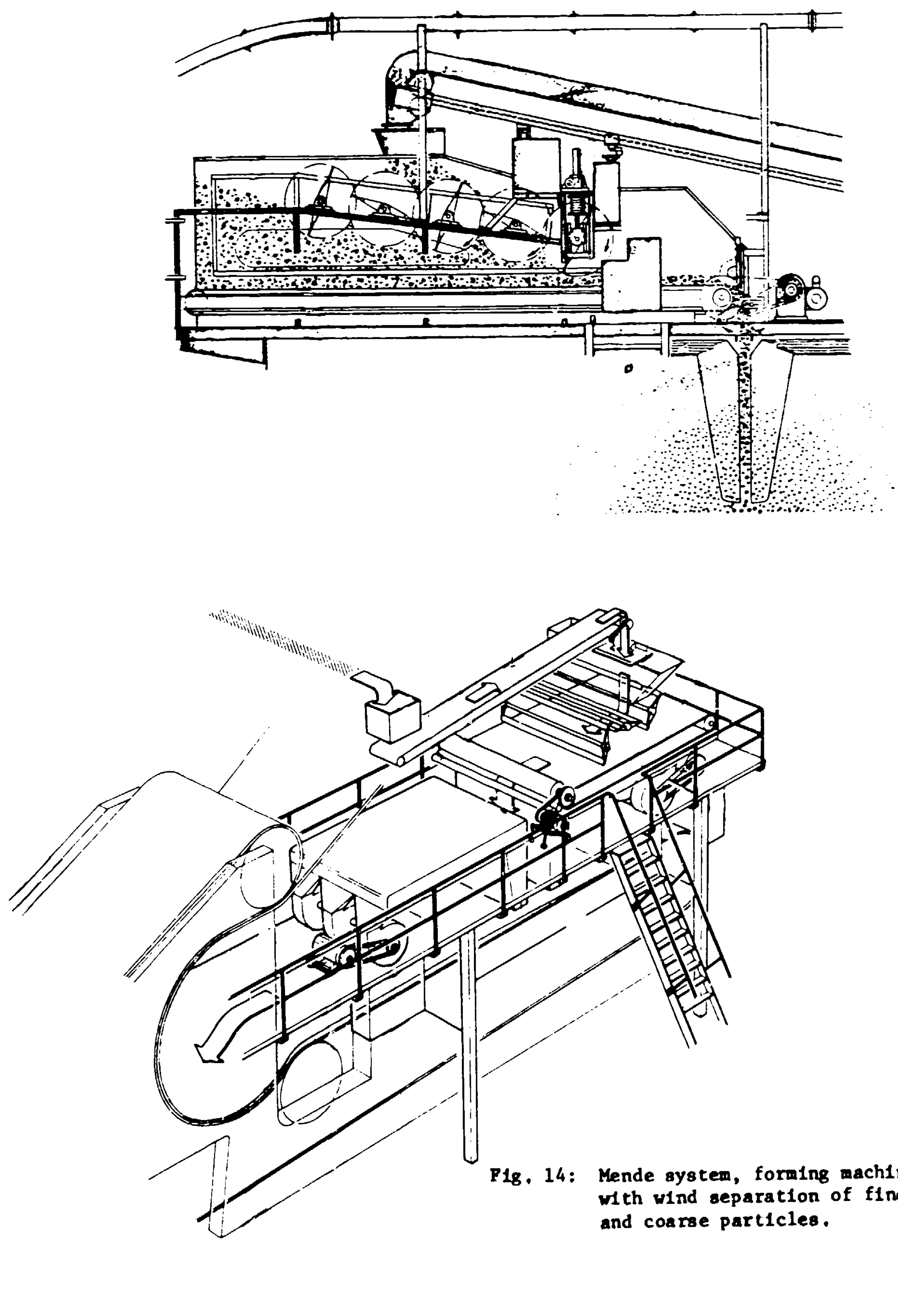


Fig. 14: Mende system, forming machine with wind separation of fine and coarse particles.

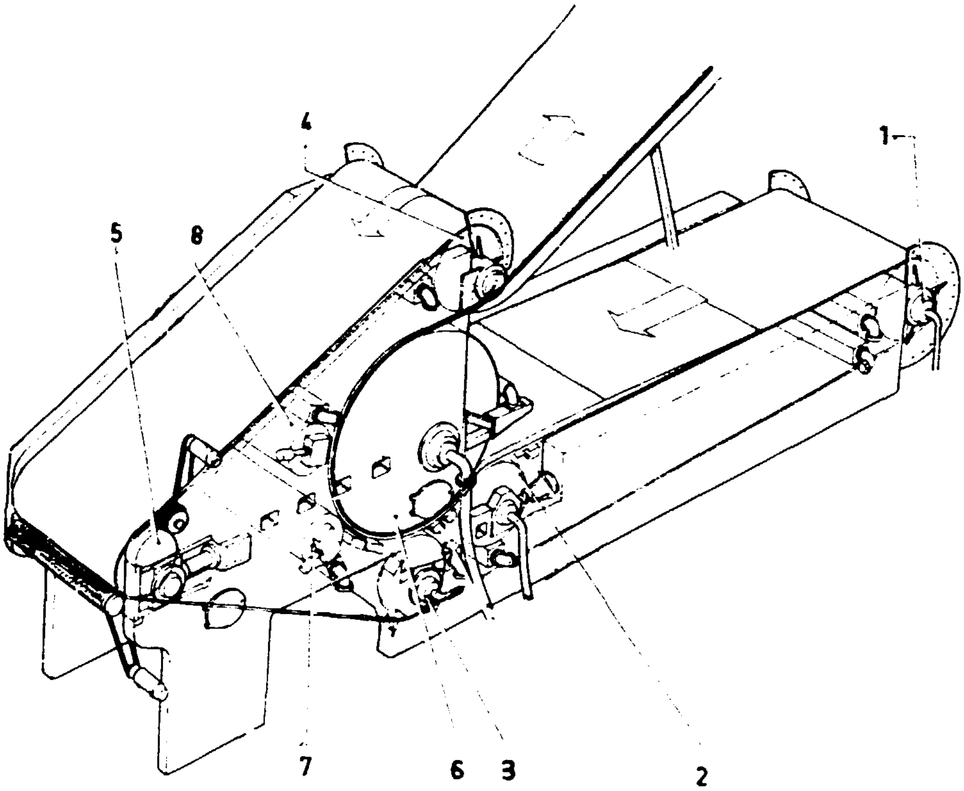


Fig. 15: Mende process: cylinder press.
1. cooling drum
2. infeed drum
3. reverse drum
4. drive drum
5. tension drum
6. hot drum
7. pressure drum
8. pressure drum

The cylinder is oil-heated to a temperature which allows the polymerization of the glue. A schematic drawing (fig. 16) gives a better idea of the principle.

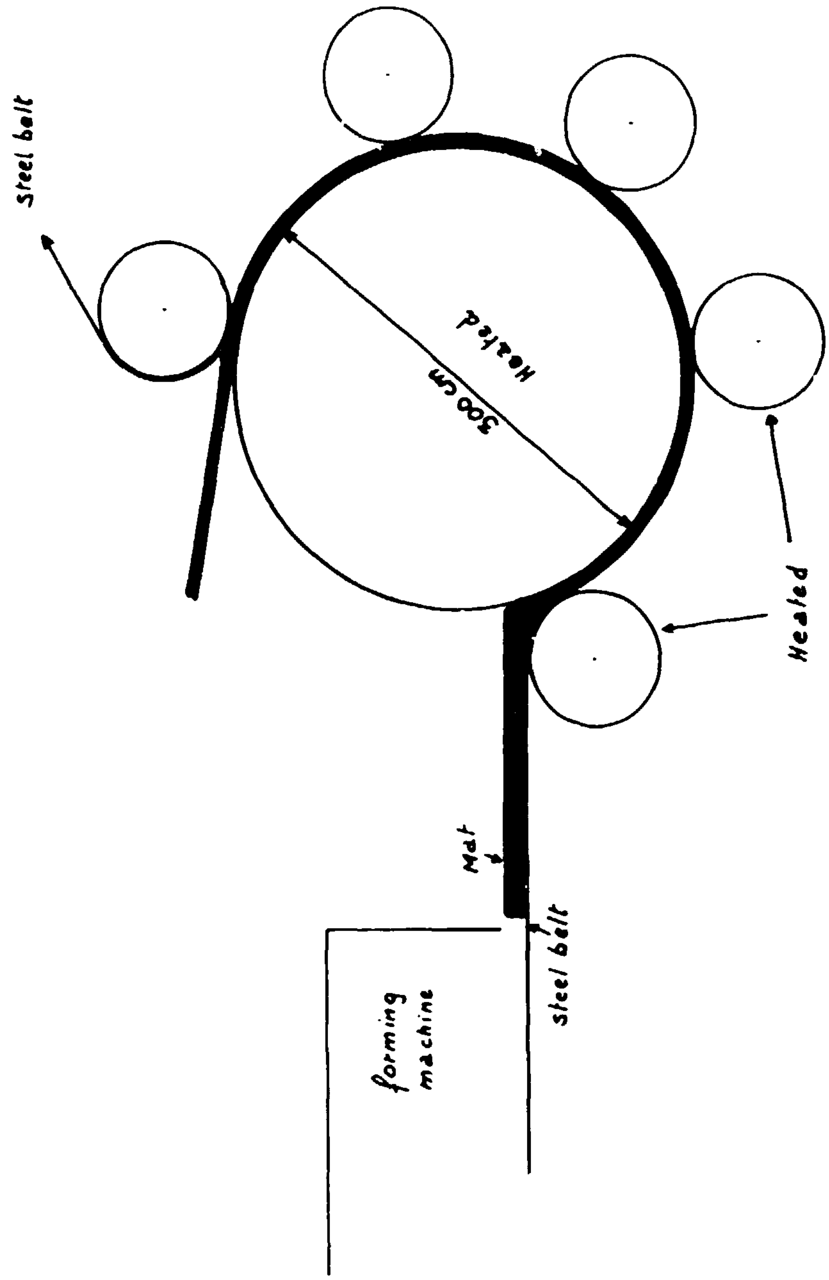


Fig. 16: Schematic drawing of the pressing cylinder in the Mende process.

The actual machine is shown in fig. 17 hereunder.

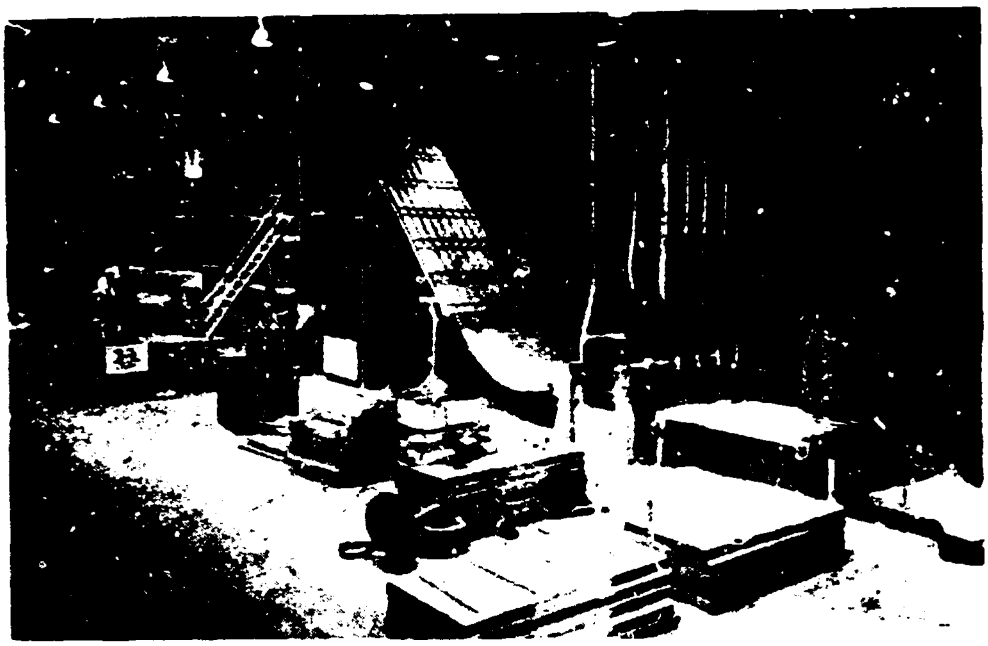


Fig. 17: Thin particle board production on a callender Mende process.

The speed of the belt depends on the board thickness and on the glueing system. Usually the speed is about 15 m/min for 3 mm board,
11 m/min for 4.2 mm board,
7 m/min for 6 mm board.

The minimum thickness is 1.6 mm and the maximum 6 mm.

The main advantages of the continuous system are:

- no limitations on board length.
- higher speed of production.

The disadvantages are the tendency of the board to bow and the main limitations of this process are to insure a perfect uniformity in thickness and to develop very high pressures.

The production of thin boards requires particular care in the wood preparation, to obtain thin particles (uniformity of distribution). The glue content, to obtain higher properties, must be great enough (dry glue: 12 percent of the dry wood). The board can receive all typical finishes, but the following qualities are required: low thickness tolerances, fine and smooth surfaces, high levels of tensile strength and internal bond.

The uses of thin board are mainly for the furniture industry (backs of panel furniture); doors (with wood surfacing) and wall decorations (see fig. 18 and fig. 19).

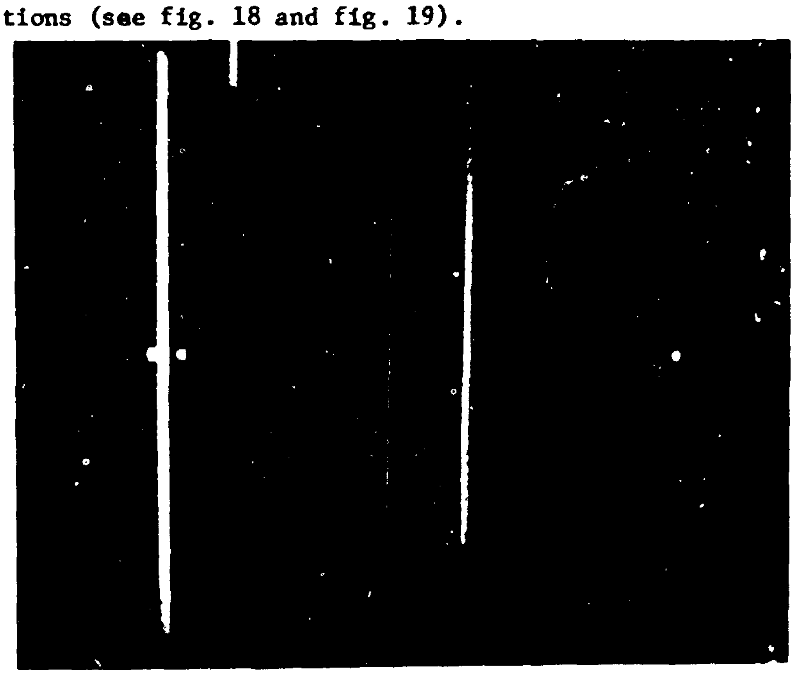
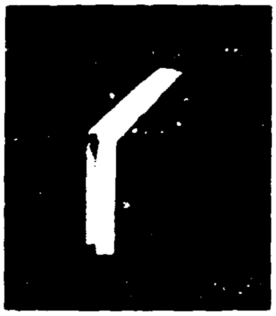
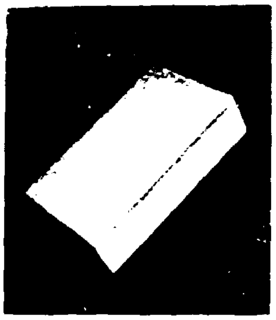


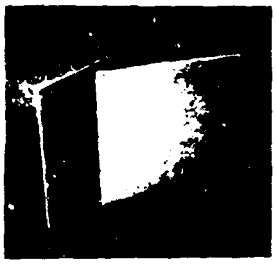
Fig. 18: Thin particle board is used as wall panels for prefabricated houses instead of plywood.



Thin particleboard is bonded with expanded polyurethane in order to make an insulating board for roofing. One side is coated with bitumen in order to improve its waterproof and fungal resistance. The sandwich board has been grooved to facilitate erection. This sandwich board has satisfied three needs: mechanical resistance, thermal insulation and reduction in labour costs.

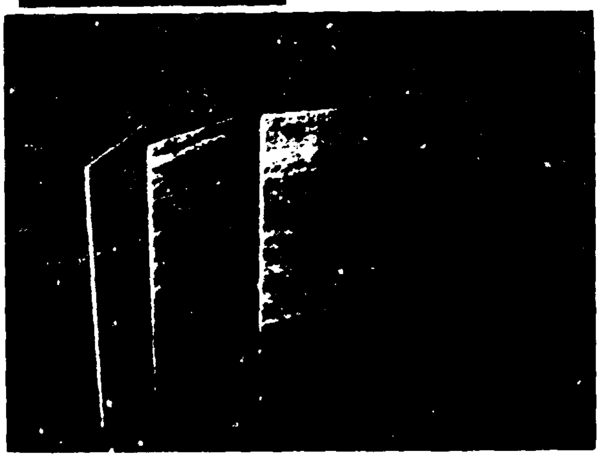


Thin particleboard is still used to build a partition wall. Both surfaces are printed to obtain a proper aesthetical and functional solution



Thin particleboard is covered on both sides with kraft paper coated with polyethylene. The tensile strength of the board is improved by about 30-40% The composite board is used for packaging.

In this case, thin particleboard has been thermoformed. This is only a laboratory test but it gives the possibilities for future use.



Thin particleboard is covered on both sides with light decorative paper for furniture framing.

Fig. 19: Typical uses of thin particle board.

This type of board can benefit from all the developments in the fields of glue and can be made with water resistant glue.

B. <u>Continuous system for thick boards</u>:

In the same spirit, many systems have been developed to produce all boards by a continuous process, the calender system being limited by the flexibility of the boards. After a certain level, it is no longer possible to increase the speed of the board transfer and the press operating time. The main semi-industrial systems are based on the principle of the cold continuous press, as shown in figures 20, 21 and 22.

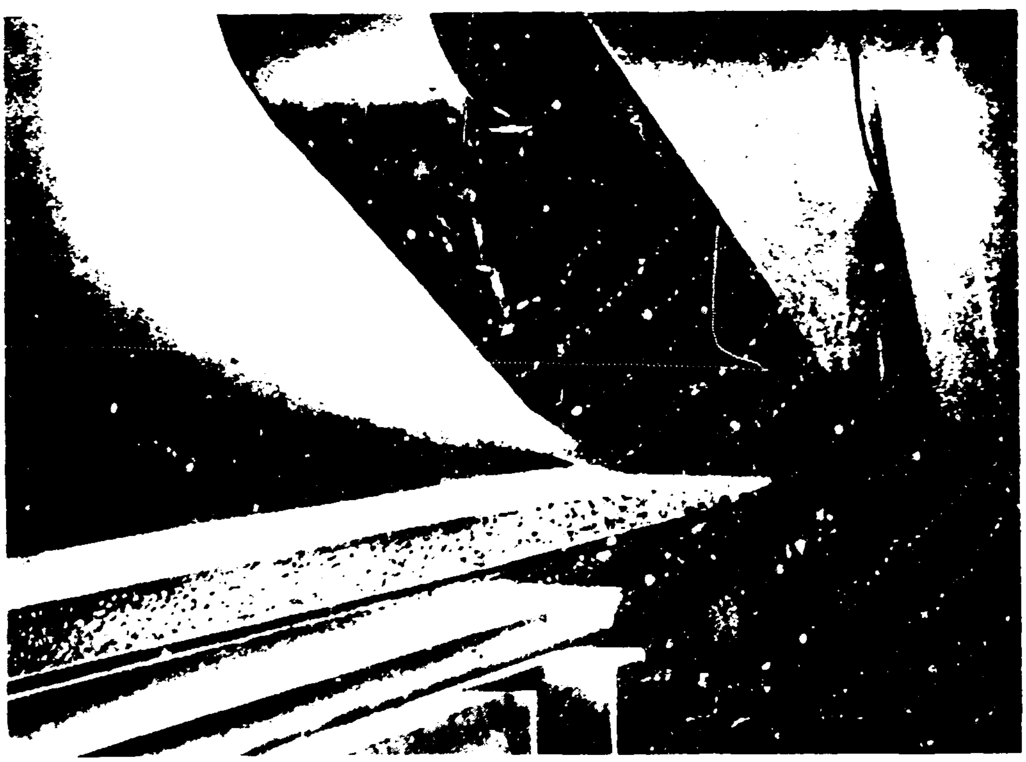


Fig. 20: Continuous pre-compressor press (cold)

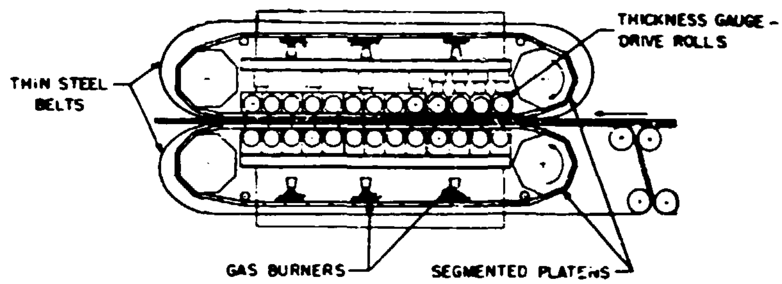


Fig. 21: Continuous press with segmented platens.

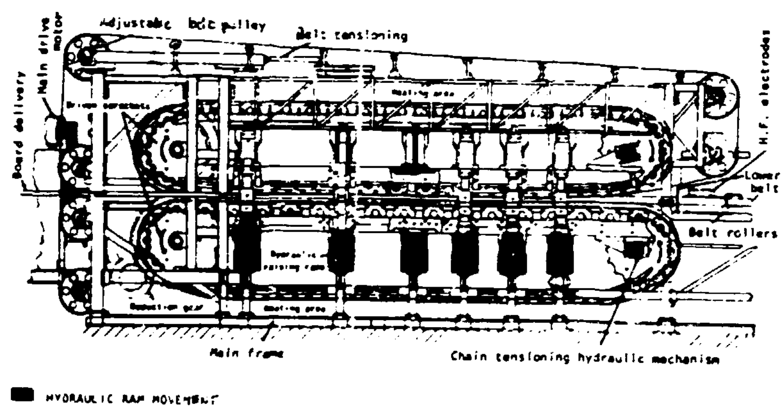


Fig. 22: Continuous press with belt rollers;

The difficulties in obtaining a board of the first quality (regularity of thickness) and preventing mechanical problems are very great.

A very new system, operating only in Belgium in one factory is the Kusters press. Basically, the principle is quite similar to that shown in fig. 22. Its main components are:

- 2 steel belts
- 2 roller chains
- 2 heated platens.

The pressure is assured by hydraulic cylinders which are arranged into frames.

This press has a length of 16 metres and 50 frames. Each frame is constituted by 7 hydraulic cylinders to cover the width of the press (2.10 m).

The pressure and the temperature are transmitted through the roller chains and the belts.

The main technological innovation is the pressure control. Indeed, each cylinder (or group of 2 or 3 cylinders) adapts its pressure automatically through a computer to the mat reaction. In this case, all variations like wood humidity, wood species, regularity of the particle dispersion, etc. are automatically compensated by the cylinder pressure. So the pressure varies both in length and in width. More than a continuous system it is really a sophisticated, technological process. With the high precision of the pressure, the thickness tolerance of the raw board is very low: 0.15 mm. The board can be surfaced with PVC or veneered without sanding.

The economical advantage of the continuous process is that the press capacity (m^3/day) is independant of the board thickness. The speed of the belt is dependant on the press length and the board thickness, in respect to the pressing factor.

The capacity is given by the following formula:

Capacity = Board thickness x Press width x Time x Belt speed.

The belt speed is linked to the specific pressing time and the press length by the following expression:

$$\text{Belt speed (m/sec)} = \frac{\text{Press length (m)}}{\text{Pressing factor (mm/sec)} \times \text{Board thickness (mm)}}$$

Further advantages of this system are that (a) there are no cutting losses lengthwise, and, (b) no time is lost to close and open the press.

C. Mat pre-heating:

To decrease the pressing time, which determines the capacity of the factory, research is being carried out at the semi-industrial scale by pre-heating the mat using a high-frequency unit.

The cost of the system and unsolved technical problems have hindered its application until now, however some processes using high frequency or a conventionally heated pre-press are available.

The pressing factors proposed by the developers of this process, using a single opening press are:

- typical process: 7 sec/mm of board thickness;
- with a heated pre-press: 6 sec/mm of board thickness;
- with a high-frequency pre-press: 4.5 sec/mm of board thickness.

The mat pre-heating appears to be a way to increase the capacity of an existing unit in the future or to extend the capacity limit of the production of the single opening process.

IV. STRUCTURAL BOARDS (WAFER BOARDS)

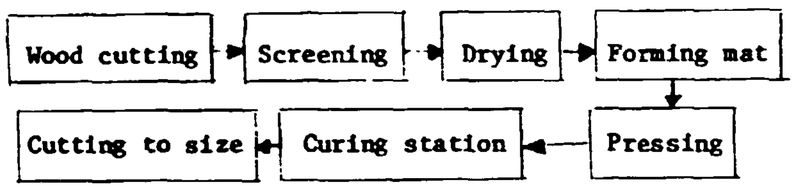
A. Technology:

Despite the rapid growth in production capacity, the waferboard manufacturing processes have remained basically unchanged since the first plant (in 1961 in Canada).

A standard wafer board can be seen in figure 23:

Fig. 23: Standard wafer board.

The typical flow sheet of the wafer board is, in principle, very similar to that of particle board manufacture. It is:



Typical process flow diagrams of Canadian and European systems are given in figures 24 and 25, on pages 36 and 37 respectively.

The particularities of the wafer board process can be described as follows:

1. Wood preparation:

The characteristics of the wood species must be low density and high resistance to compression. The typical wood species is aspen (*Populus tremuloides*). Other poplars or low density softwoods can be used.

This choice is motivated by the necessity to obtain a very high densification ratio.

On the other hand, the wood should be of good quality, without decay and with an optimum moisture content to obtain a maximum yield of particles with the following characteristics: length: 70 mm, width: 12 mm, thickness: 0.3 mm.

The wood must be debarked before cutting.

The machinery to make the particles is usually of the drum type.

The screening must be precise to extract fines or too small particles.

In fact, wood preparation is one of the most important stages of the process and great care should be exercised to obtain a maximum of particles with the required sizes. The higher the severity of preparation and screening, the more the quality of the products improves. The economy of production is largely affected by the yield of the operation and is linked to the availability and the quality of raw materials.

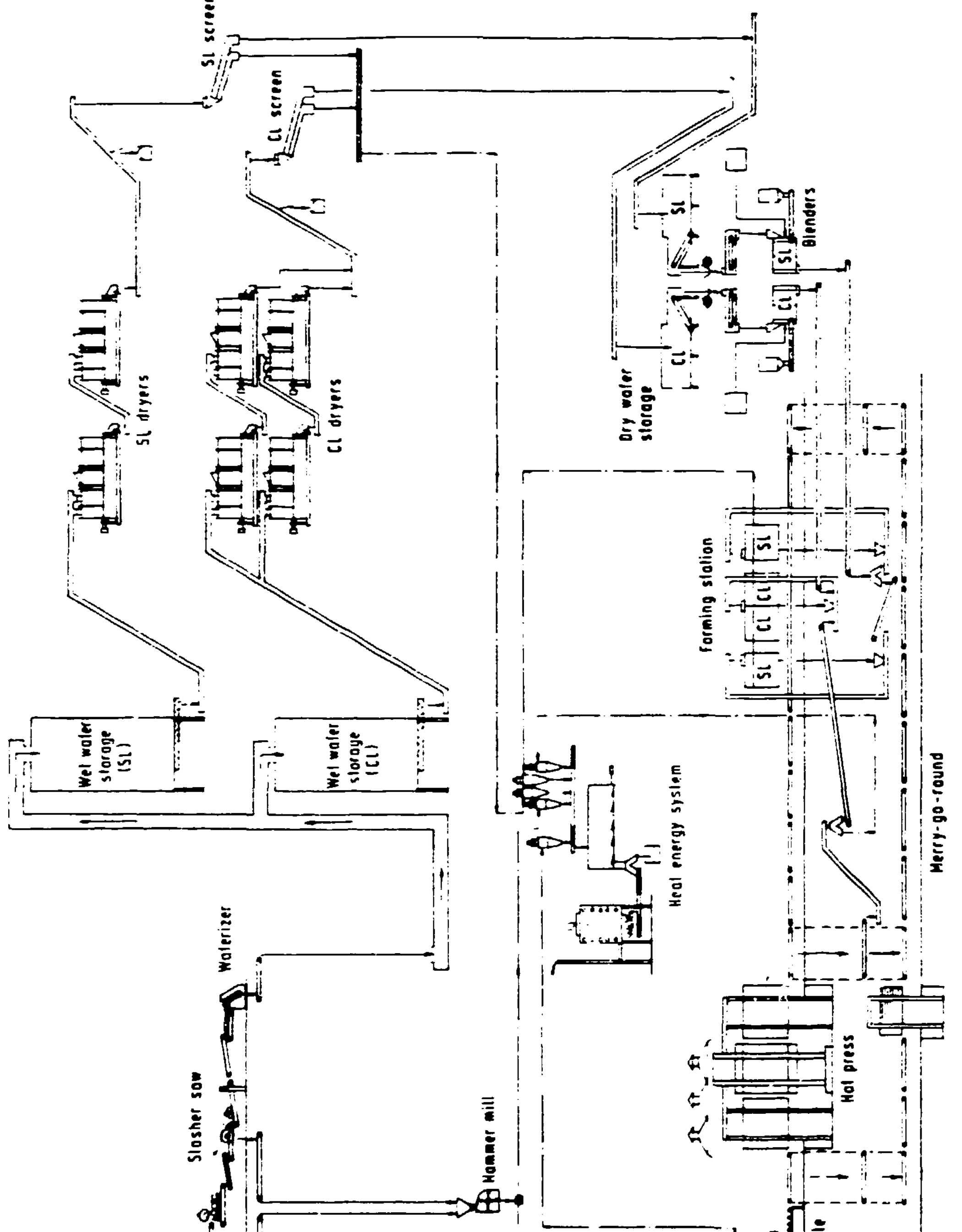


Fig.24: Typical flow system in a Canadian waferboard plant.

2. Drying:

The drying of particles must be done slowly at low temperature (175°C) with an indirect thermo oil heated dryer of the rotary bundle type. The rotary suspension drum type, with direct heating at high temperature (800-1000°C) is too drastic and breaks too many particles. The drying is slow and the final moisture content should be between 5 and 10 percent depending on the specific process used. The particles must be handled carefully to minimize wafer breakage and generation of fines. This can be achieved using a drag chain conveying system

3. Glueing:

The use of liquid thermosetting glue is not recommended because of the increase of the moisture content of the mat and the high densification ratio would increase the risks of blowing during pressing.

The glue generally used is a phenolic glue, in powder form, with a low alkali content to preserve the physical properties of the product. The glue is applied by air-atomizers. The glue ratio is between 2 and 3 percent of dry wood. The powdered glue is mixed with the particles in big rotary cylinders. To increase the quality of the board and to have a better spread of the glue on the wafer surface, a wax is added in the blender (1 to 2 percent of the dry wood). The wax is added in a soft form by a heated spray, just before the blender. The low glue ratio is possible because of the high efficiency of the glueing resulting from the densification ratio and the extreme fineness of the dry glue.

4. Forming mat:

The forming machine must be adapted to the very low bulk density of the wafers (40 to 60 kg/m^3), especially to prevent the formation of bridges in the particles silo.

The forming station is presently the main field for structural board development. To increase the rigidity of the product and to try to be as similar as possible to plywood, the wafers are oriented in one or more directions (see below). In the same way, the mat will become a three-layer board (with separate preparation of faces and core wafers, with modification of the size of the wafer, their moisture content, etc.).

The main developments in the structural boards field can be summarized under the following classification:

Flake boards: small wafers: 30 x 4 x 0.3 mm
randomized
one or three layers.

Structural boards: (Waferboards)
- Standard
  Wafers: 70 x 70 x 0.5 mm
  randomized
  one or three layers
- Waferboard plus
  three layers faces: oriented strands
  cores: randomized wafers
- Oriented waferboard:
  three layers: faces: oriented parallel to board length
  core: oriented perpendicular to board length

The machinery to realize the alignment of strands is specific to each particular process.

The particle alignment can be obtained electrostatically or mechanically. Figures 25 and 26 show some particular systems.

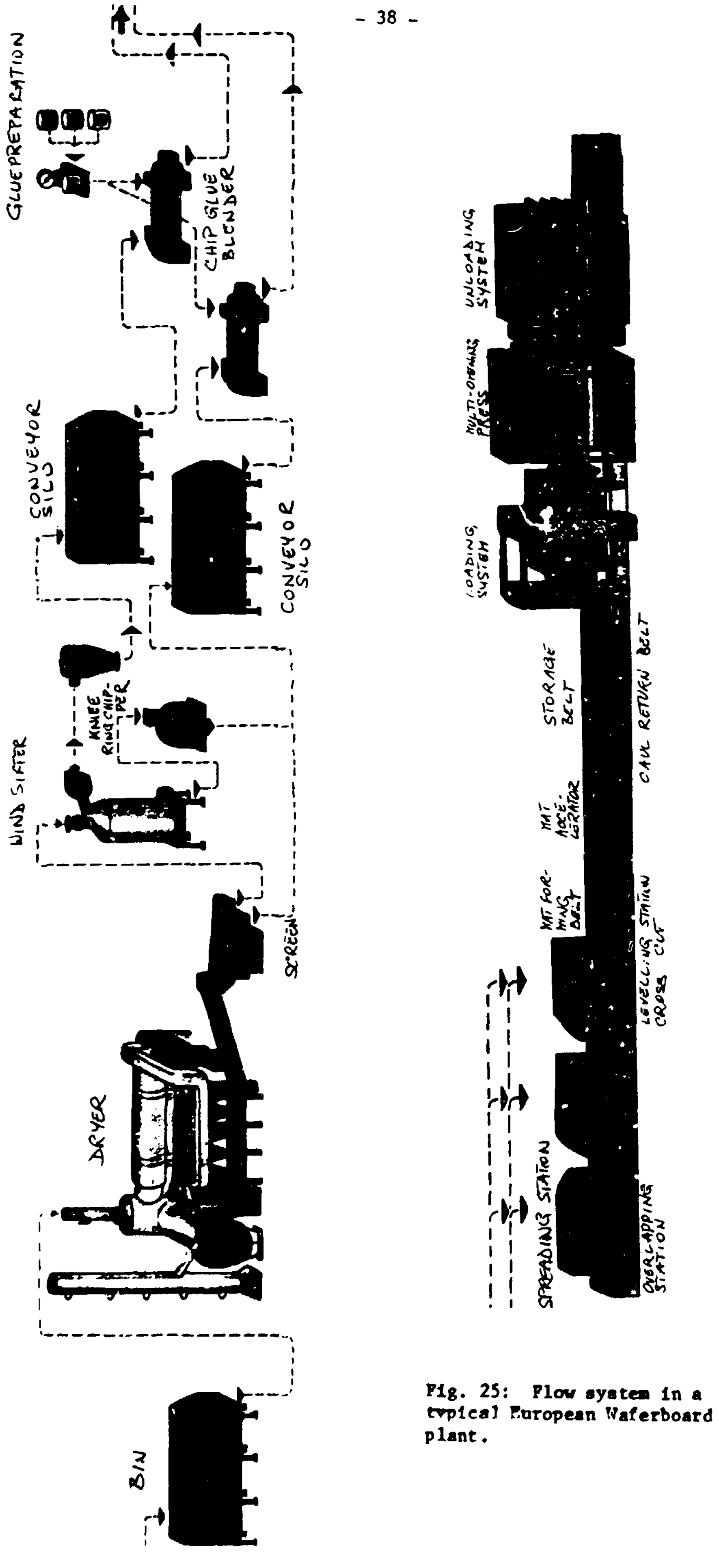


Fig. 25: Flow system in a typical European Waferboard plant.

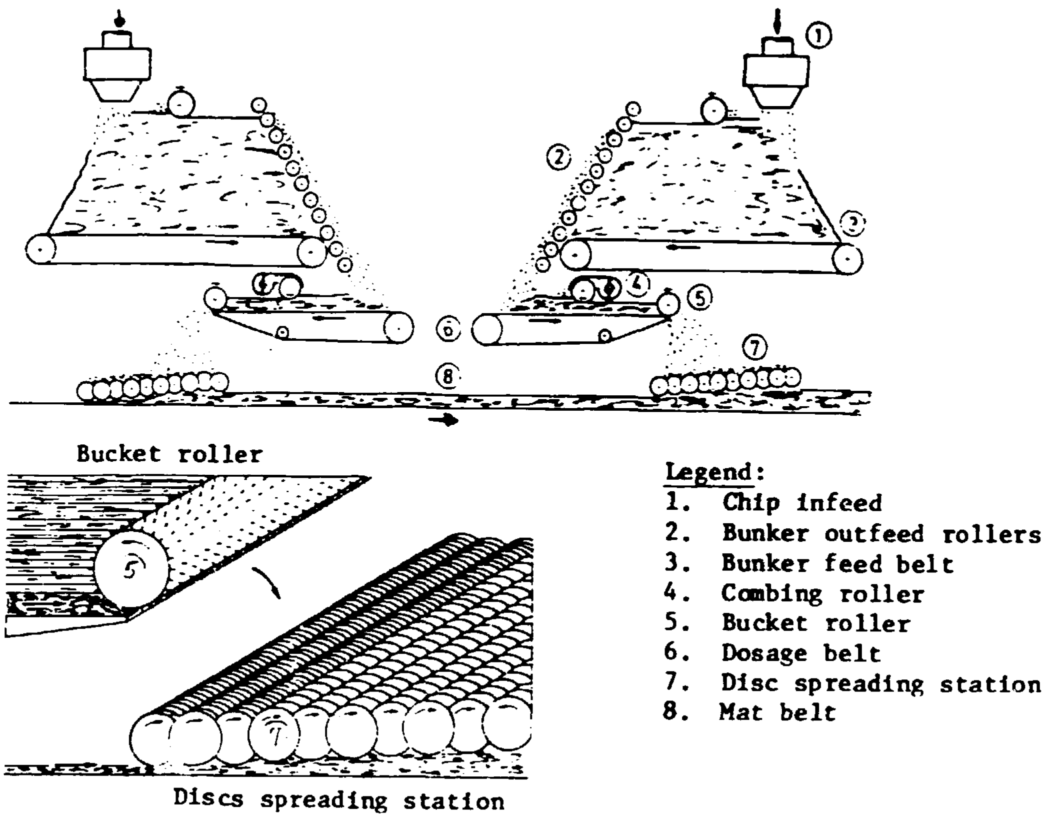


Fig. 26: Particle alignment in oriented strand boards: mechanical systems using rotating discs. Mat forming of oriented strand boards (OSB)

In electrostatic system the particles are oriented by polarization of particle. The quality of the alignment is related to the electrical power system and is also dependant on the particle's moisture content.

The mechanical systems are specific to each process and their reliability is higher, but the length/width ratio must be the highest possible to obtain a maximum percentage of particles correctly oriented. Indeed, the board properties, from randomized distribution to perfect alignment, are directly proportional to the percentage of alignment. Fig. 27 shows an impressed mat of oriented strand board emerging from the forming station.

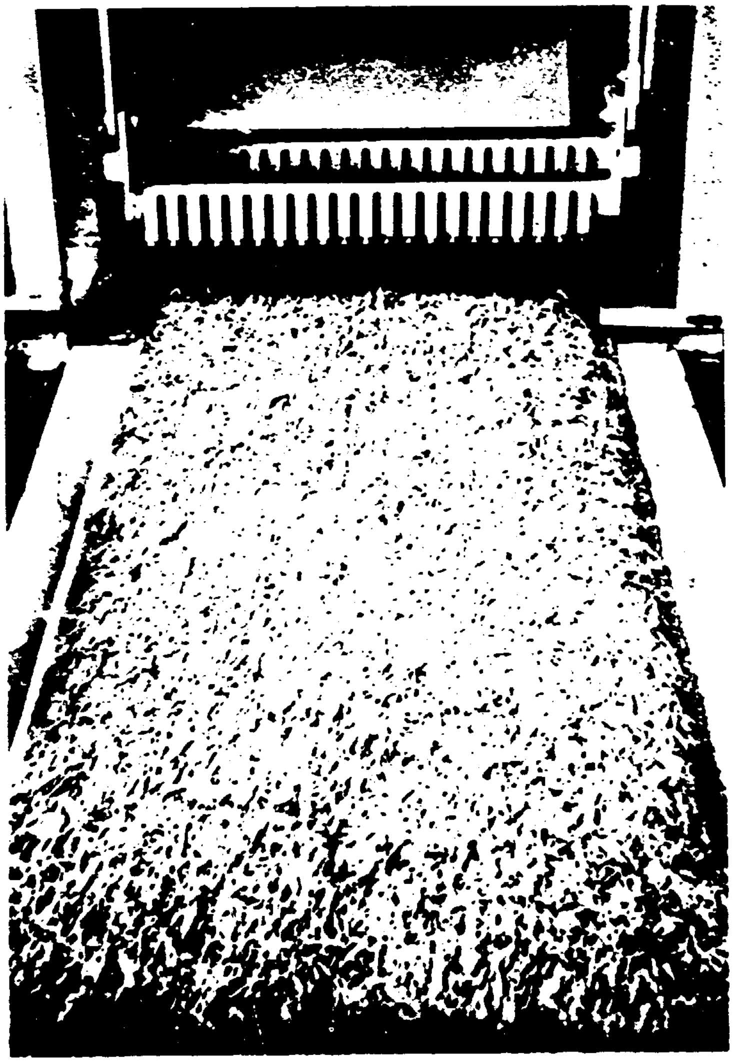


Fig. 27: Mat of oriented strand board emerging from the forming station

As the percentage of particle alignment increases, so does the modulus of elasticity, while, the linear expansion decreases (see fig. 28).

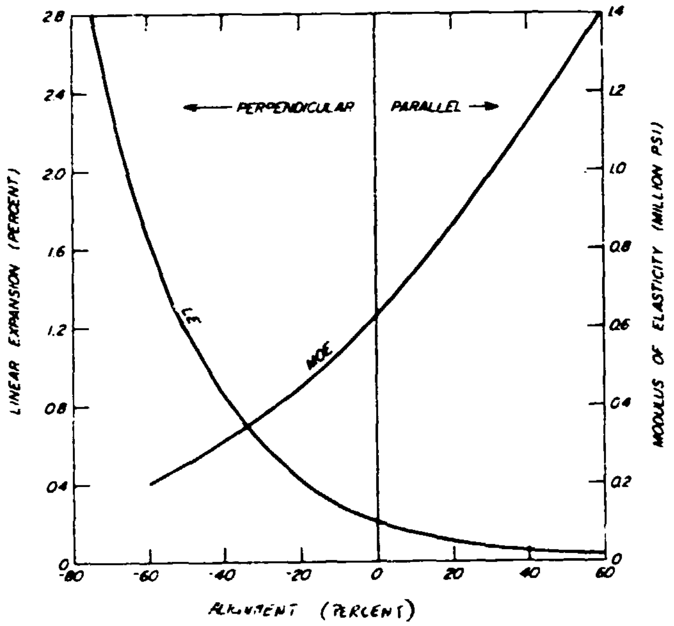


Fig. 28: Percent of flake alignment vs. linear expansion (LE) and modulus of elasticity (MOE).

5. Pressing:

Temperature:

The mat pressing is achieved at higher temperatures (200 to 220oC) than typical particle board for two reasons:

- the mat moisture content is lower and the transmission of temperature through the mat is more difficult;

- the phenolic glue needs a higher temperature for curing, specially since it has a low alkali content.

Pressure:

The pressure is also higher (30 to 40 kg/cm^2) because of the high densification ratio.

The press closing time has to be very short to prevent the pre-curing of the glue on the mat surfaces. This point is very important for the surface quality of the structural boards since they are generally used unsanded.

Curing station:

After pressing, the boards are stacked at 100^{o} to $150^{o}C$ to achieve the full polymerization of the glue.

B. Properties:

The typical parametres of the fabrication and properties are summarized in Table 1 hereunder.

TABLE 1: Manufacturing characteristics and properties of various types of waferboard.

A. Manufacturing characteristics:

	Typical wafer board	wafer board plus	Oriented waferboard
Wood species	Poplar	Poplar	Poplar
Wafer size:			
face (mm)	72x72x0.5	72x6 to 36x0.5	72x6 to 36x0.5
core (mm)	36x36x0.7	36x36x0.7	72x6 to 36x0.7
Mat moisture content:			
face (percent)	6	6	6
core (percent)	2	2	2
Glue content (powdered phenol percent of dry wood)			
face	2.5	2.75	2.75
core	2.25	2.25	2.5
Soft wax (percent of dry wood)			
face	1.5	1.5	1.5
core	1.5	1.5	1.5
Pressing temperature	200°C	200°C	200°C
Pressing factor	24 s/mm	24 s/mm	24 s/mm
Board density	650 kg/m^3	650 kg/m^3	650 kg/m^3

B. Properties:

	Typical wafer board	waferboard plus	oriented waferboard
MOR parallel to face N/mm^2	24	50	54
perpendicular to face N/mm^2	24	18	18
MOE parallel to face N/mm^2	3,600	6,000	8,000
perpendicular to face N/mm^2	3,600	1,500	2,000
Internal bond	0.5	0.5	0.5
Linear expansion parallel to face(percent)	0.15	0.10	0.08
perpendicular to face (percent)	0.15	0.15	0.12

This table shows that:

1. the standard waferboard is perfectly isotropic;

2. the orientation of the face wafers increases the modulus of rupture (MOR) and the modulus of elasticity (MOE) in the direction of the board length but decreases the strength in the opposite direction. The dimensional stability is better in the direction of orientation;

3. the orientation of the face particles with a perpendicular orientation of the core particle (with an increasing of the particle length and the glue ratio) gives a greater MOR and MOE in both directions and a higher dimensional stability.

In conclusion, the orientation of the wafers allows an increase of the strength and the rigidity in the direction of the board's length, but decreases the level of the same properties in the opposite direction. The board becomes anisotropic.

The main properties with reference to a typical particle board and to plywood are summarized in Table II hereunder.

Table II: Main properties of various types of wood based panels

Properties	T.P.B.	B.P.B.	W.B.	W.B.+	O.W.B.	N.American Softwood Plywood
Density (kg/m^3)	650	720	650	650	650	500
MOR (N/mm^2)						
//	18	20	24	50	54	60
⊥	18	20	24	18	18	40
MOE (N/mm^2)						
//	2500	3300	3600	6000	8000	7000
⊥	2500	3300	3600	1500	2000	4000
T.S. (N/mm^2)	0.5	0.7	0.5	0.5	0.5	0.8
L.E. (percent)						
//	0.20	0.15	0.15	0.10	0.08	0.06
⊥	0.20	0.15	0.15	0.15	0.12	0.12

Legend:

T.P.B.	Typical particle board
B.P.B.	Building particle board
W.B.	wafer board
O.W.B.	Oriented wafer board
W.B. +	Wafer board plus
MOR	Modulus of rupture
MOE	Modulus of elasticity
T.S.	Tensile Strength
L.E.	Linear Expansion
//	parallel to face
⊥	perpendicular to face

This table shows that the strength properties of waferboard reach those of plywood, but it is heavier. The use of wafers, instead of typical particles, allow an increase in strength without increasing the board density and gives better dimensional stability.

One of the most important points is the resistance to water. It is clear that plywood remains the better product for the more demanding end uses, but the use of powdered phenol glue of low alkali content with high quality particles allows waferboard to reach a very high level compared to typical particla board.

C. USES AND ECONOMICAL CONSIDERATIONS:

Structural board, developed since the early 1960's in Canada and in the United States of America, remains a typical North American product because of the following two reasons:

a) Economic reasons:

The structural boards are used for general sheathing, i.e. side walls, roofs and sub-floors. They are an acceptable all purpose substitute for plywood. The success of the structural board in Canada (1 million m^3/year) and in the United States of America can be explained by its cost in relation to other competing board products particularly softwood plywood.

The increase of the selling price of plywood (fourfold between 1967 and 1977) is explained by the difficulty in obtaining wood of the required quality, and due to the increase in the manufacturing costs.

The selling price of waferboard is about 15 percent lower than that of plywood but, for the same structural use, the customer must use a greater thickness (15 percent). The advantages consist in a better surface quality (aspect, smoothness), a higher surface hardness and a very good thickness uniformity.

b) Technological reasons:

Through the manufacturing process of structural board, it appears that the raw material processing is the key to good products.

The preparation of the wafers must be made carefully, using only logs of a low density wood specie with good compression strength, debarking them to keep this unfavourable raw material out, flaking in good moisture conditions, removing dust and unsuitable particles.

Structural board is made from 100 percent perfect particles, as originally in the first typical particle board. The physical and mechanical properties of typical particle board are decreasing with the acceptance of bark, sawdust, wastes, etc. resulting in structural board appearing to be a new product of high quality.

Some end uses are given in figures 29 to 38.

Fig. 29: Use of waferboard as a decorative ceiling.

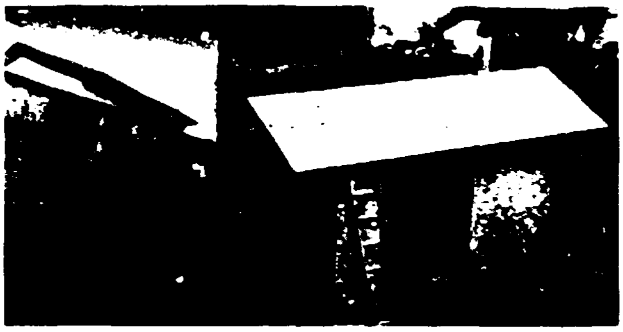


Fig. 30: Waferboard used for garden construction

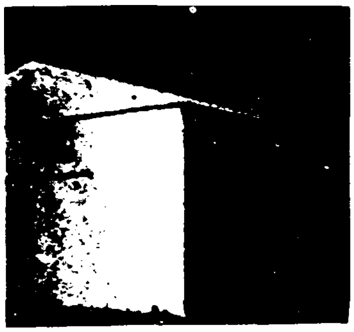


Fig. 31: Unfinished waferboard on a warehouse

Fig. 32: A waferboard fence with a stain finish.

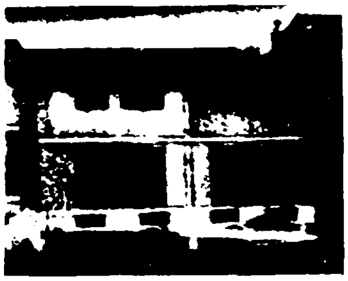


Fig. 33: Waferboard used as sheathing in residential construction.

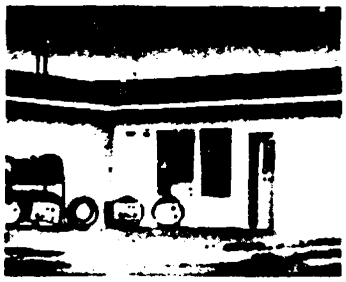


Fig. 34: A service station with exterior cladding of painted waferboard.

Fig. 35: Waferboard used as interior cladding.

Fig. 36: The characteristic mosaic appearance of waferboard after two years of unprotected exposure to the weather.

Fig. 37: Waferboard used in do-it-yourself construction.

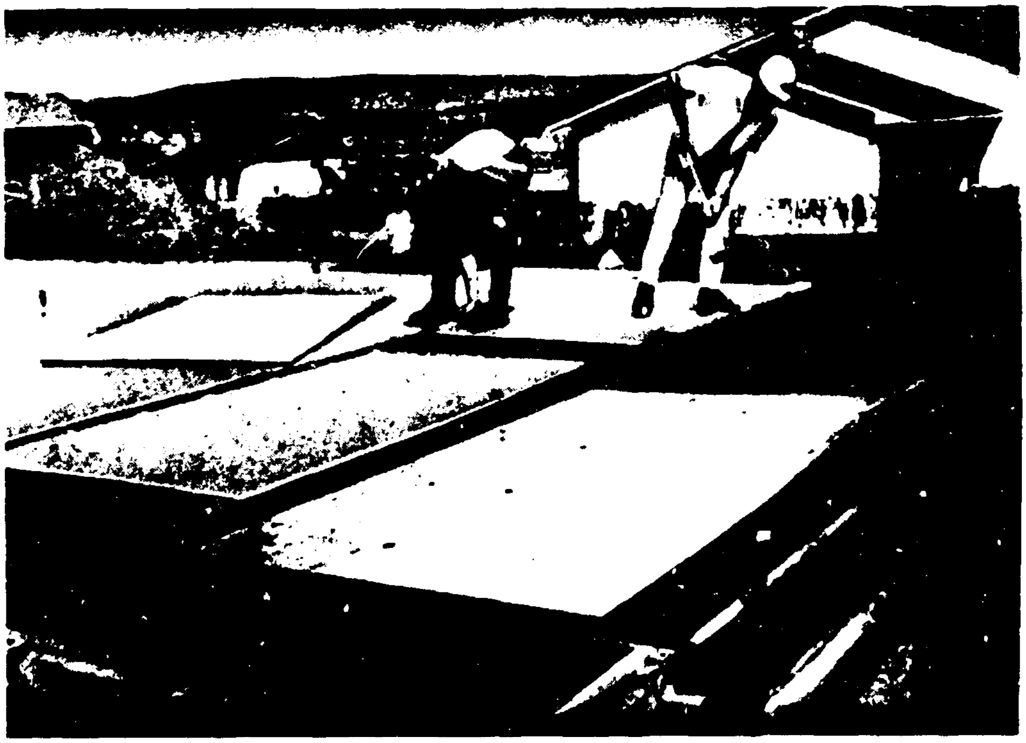


Fig. 38: Use of waferboard as load-bearing flooring.

V. CEMENT BOARD:

A. Technology:

Cement board production consists of mixing cement, or any other mineral binder, and wood, in the form of wood-wool or particles, to obtain panels of the required sizes.

Actually two kinds of boards are made:

- low density board, with wood-wool (with a density of approximately 650 kg/m^3) (see fig. 39)
- high density board, with particles (with a density of approximately 1250 kg/m^3) (see fig. 40)

The principles of manufacture are quite similar, but the properties and uses are very different. For this reason, the two processes will be analyzed separately.

Fig. 39: Woodwool cement board (low density board)

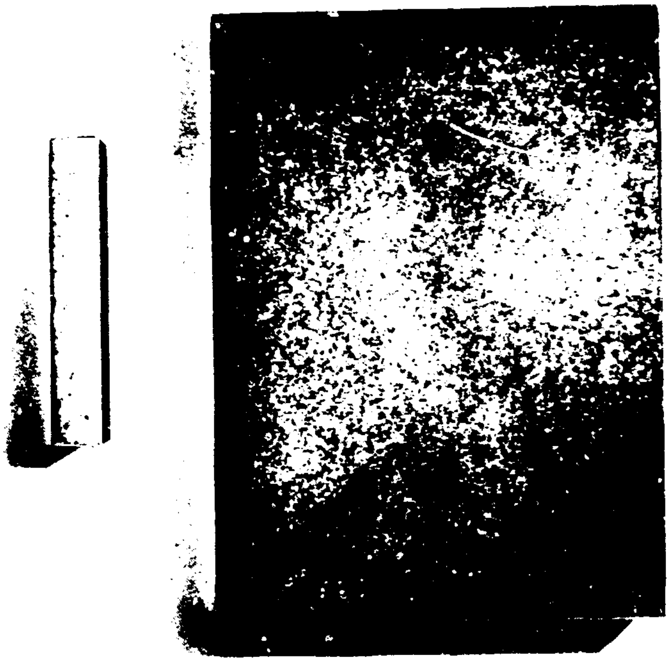
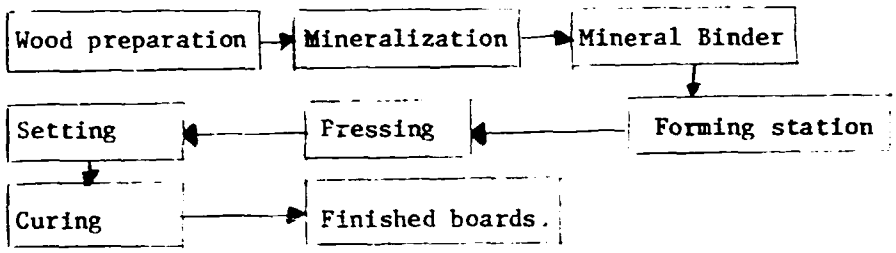


Fig. 40: Cement bonded particle board (high density board)

1. Principles:

The main production phases are given in the following scheme:



The wood is cut to the appropriate form (wool or particle). To prevent the cement setting inhibition by sugar or other wood extracts, it is necessary to immerse the wood in an accelerator solution of salts ($CaCl_2$, Na_2SiO_3).

The powdered cement is mixed with the wet wood. After spreading out of the fibres in a mould, the mat is pressed to the required thickness. The mat is removed from the press but the pressure is maintained for 24 hours to permit a first setting of the cement. The moulds are recycled after the boards are removed The board is placed in a conditioning room for the cement to cure fully, or stored in the open.

The technology for this production is very simple, it can be mechanized or not, and gives products of very high quality. However, the parameters enumerated hereunder appear to be very important.

2. Wood-wool cement board:

2.1 Wood-wool preparation:

The wood-wool is made from pieces of wood, roundwood or slabs approximately 50 cm long.

Figure 41 shows a typical machine.

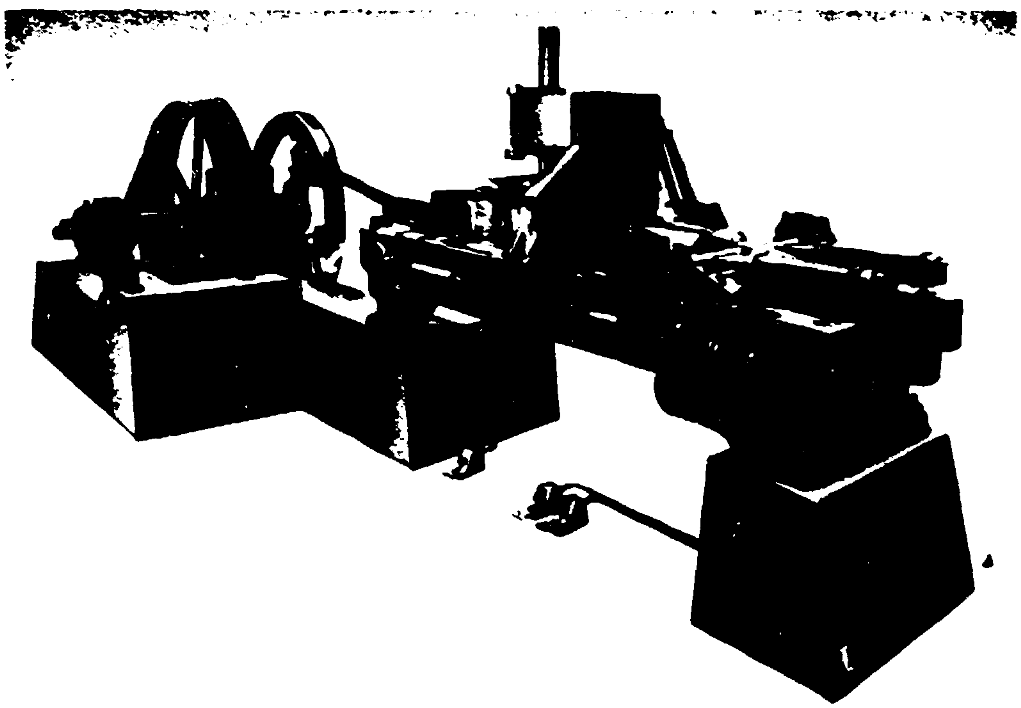


Fig. 41: Wood-wool making machine

The wood remains fixed and the table with knives moves to and fro. This machine can produce wool from slabs.

The standard dimensions of the wool to give good board strength at a low density are: length 10 to 50 cm, width 2 to 5 mm, and thickness 0.2 to 0.7 mm.

To obtain a fibre of maximum length, it is necessary to work wood with no decay or defects, with a correct grain orientation and at a good moisture content (20 to maximum 25 percent). Too high a moisture content gives bad mineralization, too dry wood makes too much dust and gives too short fibres. The generation of fines must be as low as possibel because they reduce board strength.

The choice of the wood species is very important because of cement inhibition. This problem shall be examined later.

In practice, wood species like spruce, poplar and pine produce good boards.

2.2 Mineralization:

Figure 42 gives the general schematic lay-out of the standard manufacturing process. (see page 59)

The wood-wool must be mineralized to accelerate the cement setting and to increase the board's strength. The chemical products used are generally specific to each process, but calcium chloride ($CaCl_2$), sodium silicate (Na_2SiO_3) and magnesium chloride ($MgCl_2$) are largely used. After the wood-wool is immersed in the salt solution (1 to 3 percent), the excess water is removed to obtain the required moisture content.

2.3 Mineral binder:

The mineral binder - cement, magnesite, gypsum or lime - is applied proportionally to the dry weight of wood and mixed with the wood-wool in a rotary drum.

The mixing must insure a good application of the binder onto the wood-wool. The standard cement used is a fast setting Portland cement, with the following composition:

Tricalcium Silicate ($3\ CaOSiO_2$) $\pm$ 48 %
Dicalcium Silicate ($2\ CaOSiO_2$) $\pm$ 27 %
Tricalcium Aluminate ($3\ CaOAl_2O_3$) $\pm$ 12 %
Tetracalcium Aluminoferrite ($4\ CaO\ Al_2O_3Fe_2\ O_3$) $\pm$ 8 %

These components hydrate upon contact with water at different speeds.

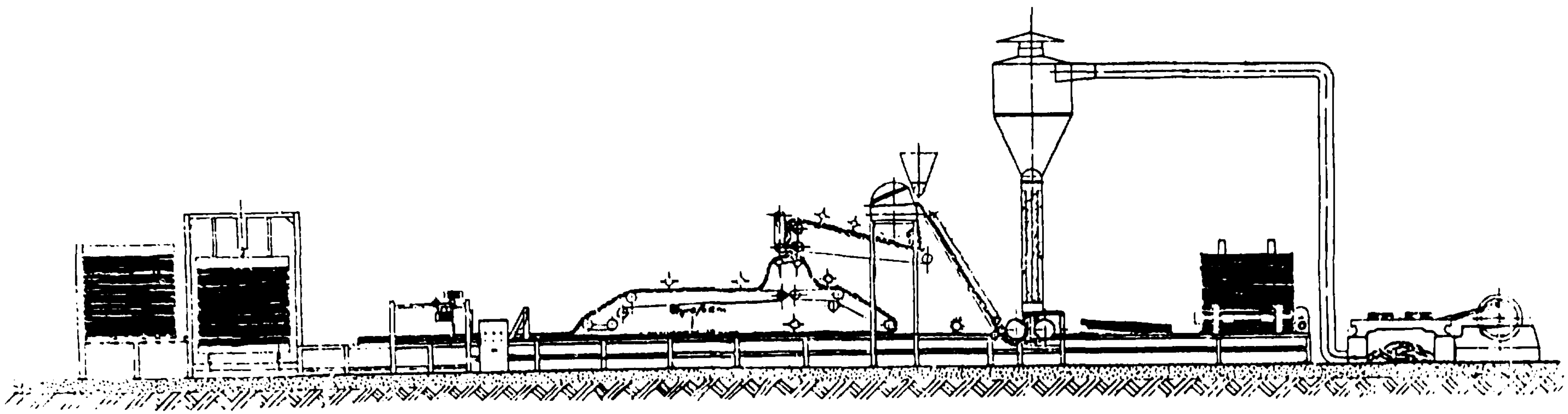


Fig. 42: Schematic layout of a wood-wool cement board plant - to produce sandwich panels.

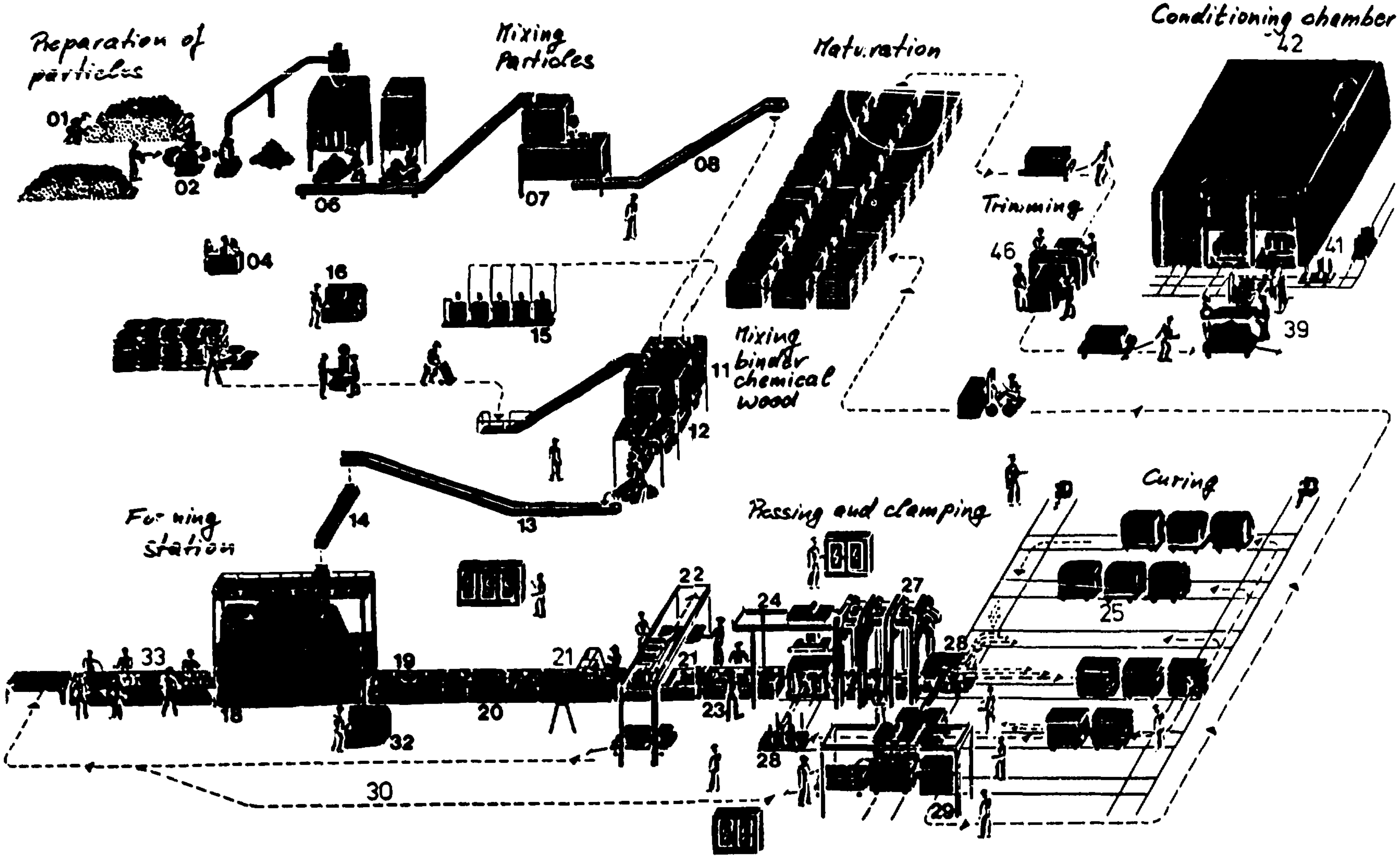


Fig. 42 a: Small-scale, labour intensive cement bonded particle board plant, capacity: 25 m^3 per day (in three shifts)

2.4 Forming mat:

The wood-wool mat is formed in a mould or by a continuous system in a mould chain. The most important parametre is the uniformity of the spreading which directly affects board properties and their variations. The process can include wood pieces in the mat to increase its rigidity or expanded polystyrene board in the core to increase the insulating properties of the product. In this case, the wood-wool is distributed in two stages (as shown in fig. 42.).

2.5 Pressing:

The pressing does not have the same importance in wood-wool cement board as in the conventional particle board process, where it is necessary to press and apply heat to reduce the mat's thickness and polymerize the thermosetting adhesive. Here, the purpose of the pressing is just to reduce the thickness. After pressing, the board pile is clamped together or a mass of concrete is laid on it for 15 to 24 hours. After this time, the cement has set enough to de-mould the boards and recycle the moulds.

2.6 Curing:

To cure the cement completely, the boards must be stocked for a time which depends on the climate, the kind of cement and the chemical additives used. Normally this time is about 28 days.

3. High density cement board:

To have the possibility to use particles from roundwood or wastes, it is necessary to densify the wood-cement mixture. The stages in the manufacture are the same as for wood-wool board except that:

- the mineralizing agent, the cement and the water are mixed together in one step.
- the pressure must be higher (up to 50 kg/cm^2)

Sometimes, it is necessary to stock the board in a heated conditioning chamber to assure a good setting of the cement and to reduce the curing time. Fig.42 a shows a schematic layout of a plant capable of producing 25 m^3 per day. Usually, the high density cement board contains a higher cement ratio (70 to 75 percent cement).

4. The main technological problems:

It has already been mentioned that some wood extracts retard or inhibit the setting of the cement. The mineral products used can accelerate the cement setting. This question has not yet been fully investigated and limits the use of some raw materials.

The hydration of cement develops a crystal structure that intergrows and interlocks with adjacent crystals, and develops bonds with wood.

The inhibitor or accelerator effect can be seen in the following figures:

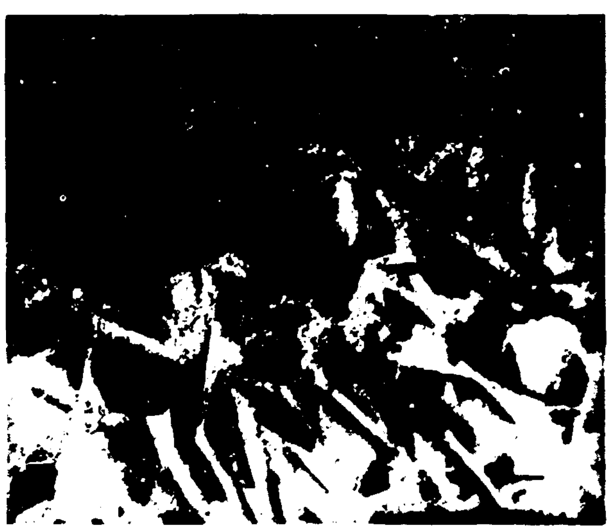


Fig. 43: Electron micrograph of hydrated cement with no additives in a cell lumen. The bar in the photo represents one micrometer.

Fig. 44: The same wood, the same cement with 3 percent calcium chloride - Note the shape of the crystals formed. The bar also represents one micrometer.

Fig. 45: The same wood, the same cement with 0.5 percent of Dextro glucose. The crystals are thin and long fibres which are not able to develop board strength. The bar represents 10 micrometres.

Practically, the effect of an accelerator or an inhibitor is very important to the mechanical properties of the board, as it is illustrated by figure 46:

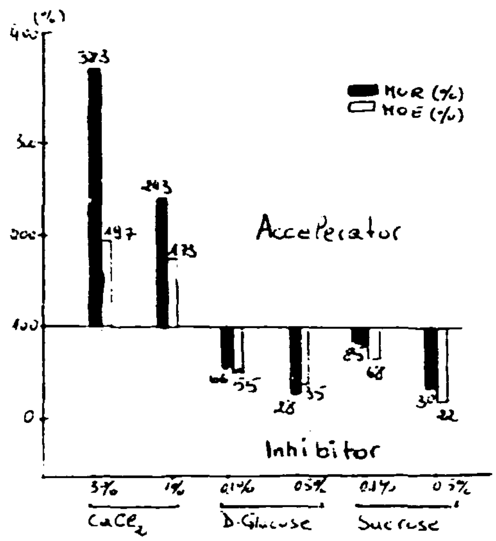


Fig. 46: Relative values for MOR and MOE in bending for boards with various additives as compared to control specimens. Values for control specimens are assumed to be 100 in this illustration.

That proves the necessity to appreciate the correct setting of the cement. The cement hydration being an exothermic reaction, the level of temperature developed by the reaction in a calorimetre is a very good indicator of the reaction quality. Fig. 47 shows the principle of a very simple apparatus used for this test, while fig. 48 shows the actual pieces of equipment.

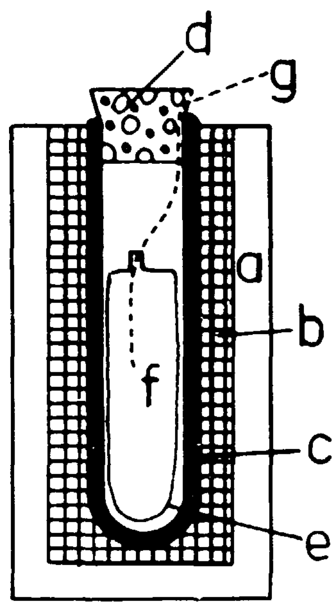


Fig. 47: Schematic drawing of calorimetre to test reaction quality.
a plywood box
b insulating material
c vacuum flask
d stopper
e plastic bag
f cement, or wood/cement mixture
g thermocouple

Fig. 48: Recording equipment to test reaction quality showing the recorder, the vacuum flask, the thermocouple and the wood/cement mixture after curing (90 percent cement, 10 percent wood)

A mixture of wood and cement is put in a well insulated bottle, with a thermocouple. The temperature developed by the hydration allows to determine whether or not inhibition problems occur. An example of this is given in figure 49.

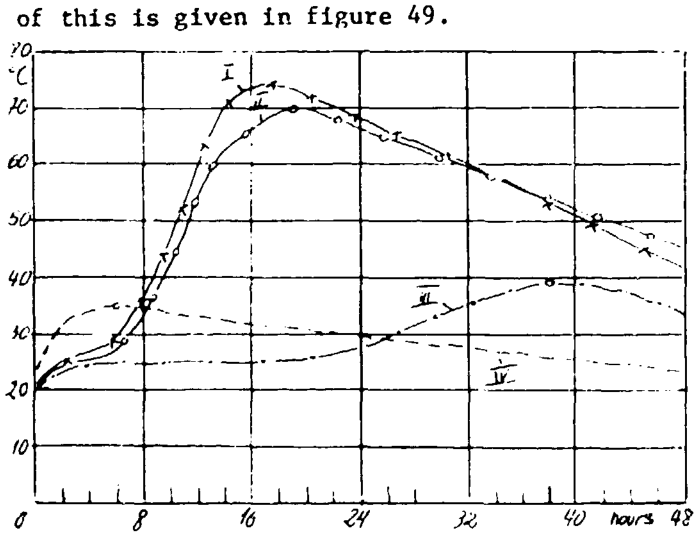


Fig. 49: Temperature curves for four wood species.

From the curve of four tested species it appears that wood specie I and II are very good, while III and IV are unsuitable.

Figure 50 shows the hydration temperature measurements for certain wood species. Such measurements determine the species' suitability for use with cement binders. Above the upper limit, the hydration temperature indicates a good cement setting and good board properties. Below, the lower limit the wood extractives inhibit the cement setting and give poor quality boards. Between the two limits it is possible to use an accelerator or a specific chemical system to achieve a correct cement setting.

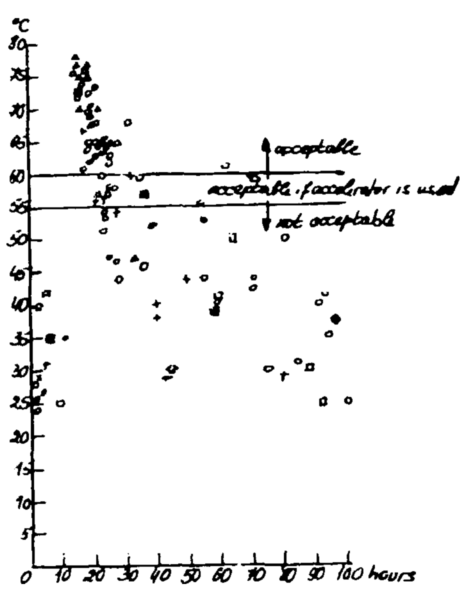


Fig. 50: Hydration temperature measurements for certain wood species. 1 = acceptable specie, II= acceptable specie if an accelerator is used, III = not acceptable specie IV= not acceptable specie. (For identification of species, see figure 3)

On the otner hand, different cements have different compositions and each component has a specific hydration temperature (120°C for tricalcium silicate 3 $CaOSiO_2$; 320°C for tricalcium aluminate 3 $CaOAl_2O_3$).

Figure 51 gives the hydration temperature of some types of cement.

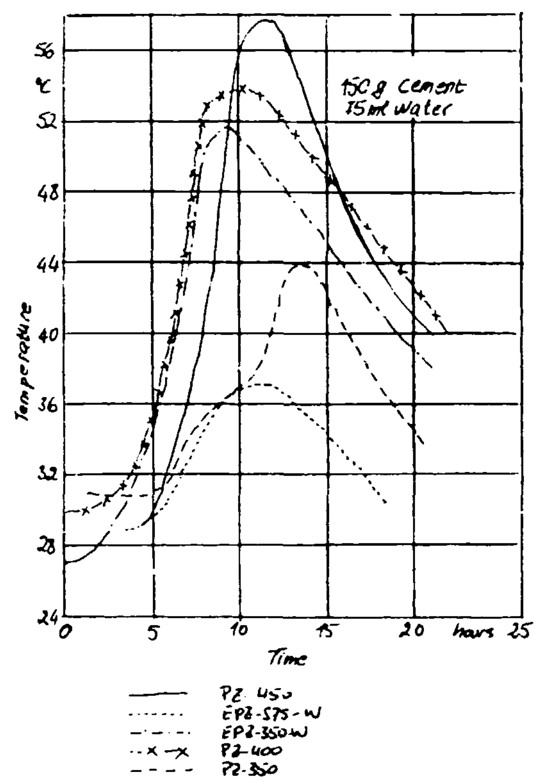


Fig. 51: The spedifications describing the cement used refer to Deutsche Industrie Normen (DIN) and the figures given refer to the strength development of the specific cement used.
The specifications describing the cement used refer to Deutsche Industrie Normen (DIN) and the figures given refer to the strength development of the specific cement used.

The higher the hydration temperature of the cement is, the higher are physical and mechanical properties of the boards.

B. Properties:

Except for the wood/cement compatibility and the availability of an appropriate cement, the process does not need sophisticated technology to obtain a very good product.

However, to maintain adequate uniformity of properties, it is necessary to control the main steps of the process. The following must be controlled:

Wood - compatibility with cement -wood species
-date of harvesting
- size of particle or wool
- wood moisture content

Salt: - nature ($CaCl_2$, Na_2SiO_3 etc)
- percentage (1 to 3 percent)
- duration of immersion

Moisture: - content after mineralization

Cement: - type and temperature of hydration
- ratio cement/wood/water
- mixing quality

Pressing: - time
- hygrothermic conditions during hydration.

Curing: - Duration

As an example, figure 52 gives the linear expansion for different times of curing as a function of board density. It appears that the more the density increases, the more the natural curing time must be great to reach stabilization.

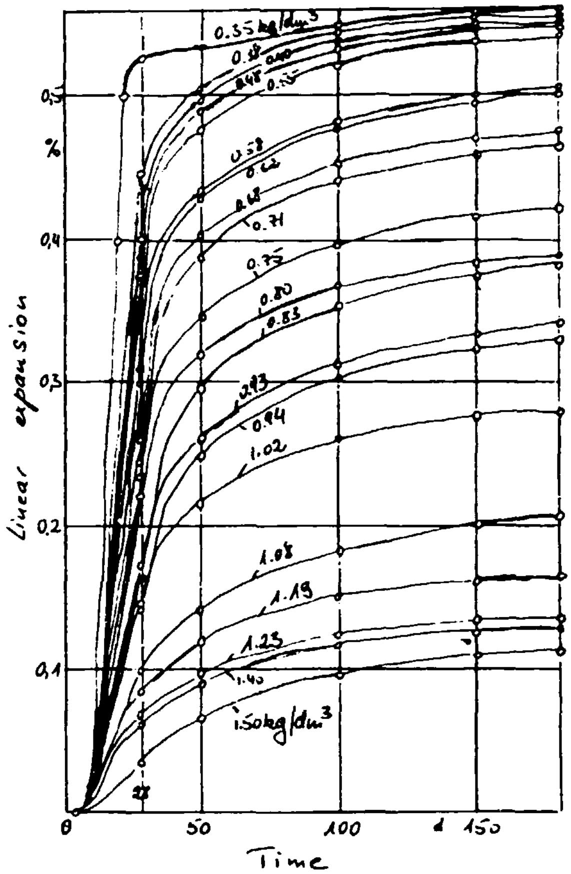


Fig 52: Relation between time, board density and linear expansion of wood-wool cement boards.

The raw material requirements for the production of wood/cement boards is given in table III hereunder.

TABLE III. Raw material requirements for the production of wood/cement board (per m3 of board)

	Low density	High density
Wood (kg)	140	270
Cement (kg)	260	730
Water (1)	600	300
Cemicals (kg)	3.5	8

The general properties of cement board are dependant on the thickness of the board. The low density board can be made from 25 mm to 100 mm thick, while the high density board is generally thinner, 8 to 40 mm.

The more interesting properties between various types of boards are given in Table IV hereunder

Properties		Cementboard (1) HD.	Cementboard (1) L.D	Particleboard (2)	Asbestos Board (3)	Gypsum Board (4)
MECHANICAL						
Raw Density	kg/m³	1200 - 1400	500/650	600 - 700	1800	850 - 1100
Thickness	mm	4 - 50	20/100	as requested	as requested	as requested
Bending strength	kg/cm2	120 - 180	15/40	120 - 200	170 - 280	low
Transverse tensile strength	kg/cm2	6 - 9	-	3 - 6	not tested	low
Swelling: 2 hours	%	0.2 - 0.6	-	6	0.5 - 0.8	destructive
24 hours	%	0.6 - 1.2	-	12	0.5 - 0.8	destructive
Moisture content	%	9 +/-3	12	9 +/-3	10	10
Compressive strength	kg/cm2	150		100	100	low
Thermal conductivity kcal/m/h°C	λ	= 0.155	0,05	= 0.120	= 0.300	= 0.300
PHYSICAL						
Screw holding	kg/cm2	140 (18mm)	-	135 (18mm)	not tested	low
Nail holding	kg/cm2	50 (18mm)	-	22 (18mm)	not tested	low
Weather resistance		resistant	id	low	resistant	destructive
Frost resistance		resistant	id	low	resistant	low
Fungus resistance		resistant	id	low	resistant	resistant
Chemical resistance		resistant	id	limited	resistant	limited
Fire resistance		resistent	id	low	resistant	limited
Sound insulation		good	Very good	good	good	good
PROCESSING						
Sawing		yes	yes	yes	no	limited
Sanding		yes	no	yes	no	no
Milling		yes	yes	yes	no	no
Glueing		yes	no	yes	no	no
Veneering		yes	-	yes	no	yes
Laminating		yes	-	yes	yes	no
Painting		yes	-	yes	yes	yes
Plastering		yes	yes	yes	yes	limited
Outdoor use		yes	yes	limited	yes	no
Indoor use		yes	yes	yes	yes	yes

The mechanical properties appear to be good for high density cement board and low for wood-wool baord. Board swelling is very low, but linear expansion (not indicated on the figure) is higher than for particle board.

The main advantage of these products with regard to particle board are, for both kinds of panels, their fire, fungus and weather resistance.

Uses:

Because of their properties (especially weather resistance), cement boards are very good and well adapted building materials. The low density and the high density boards differ mainly in their mechanical properties and in their surface quality.

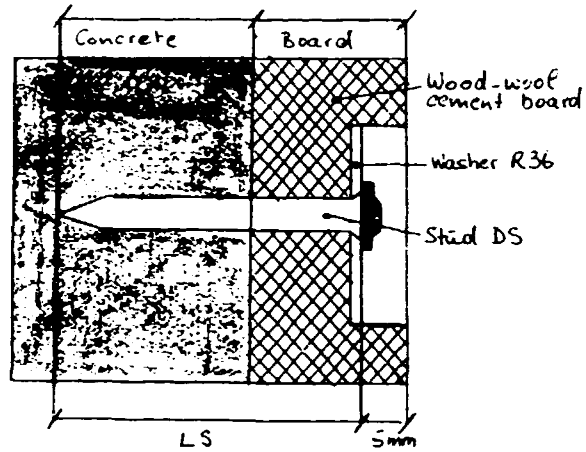
These products can be used for similar end uses but using different techniques.

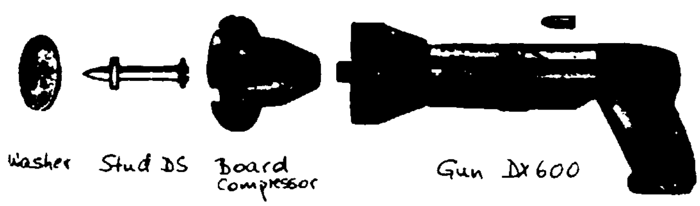
a) Wood-wool board:

Wood-wool boards have a low density and low mechanical resistance. Because of that, some very specific tools are recommended to assure an easy and correct use. One such system is shown in Fig. 53, on page 73.

Other systems exist to fix board onto concrete blocks or wood frames. Among these are systems having metal nails with plastic or metal heads, wire spirals and plastic anchors. Basically, in all cases, the ring or the large head prevents the pulling up of the board.

Thin and light iron grating is used to improve the linear shrinkage of the board and to prevent cracking at the joint of two boards when used in lost shuttering (concrete shell) construction (see Fig. 54).





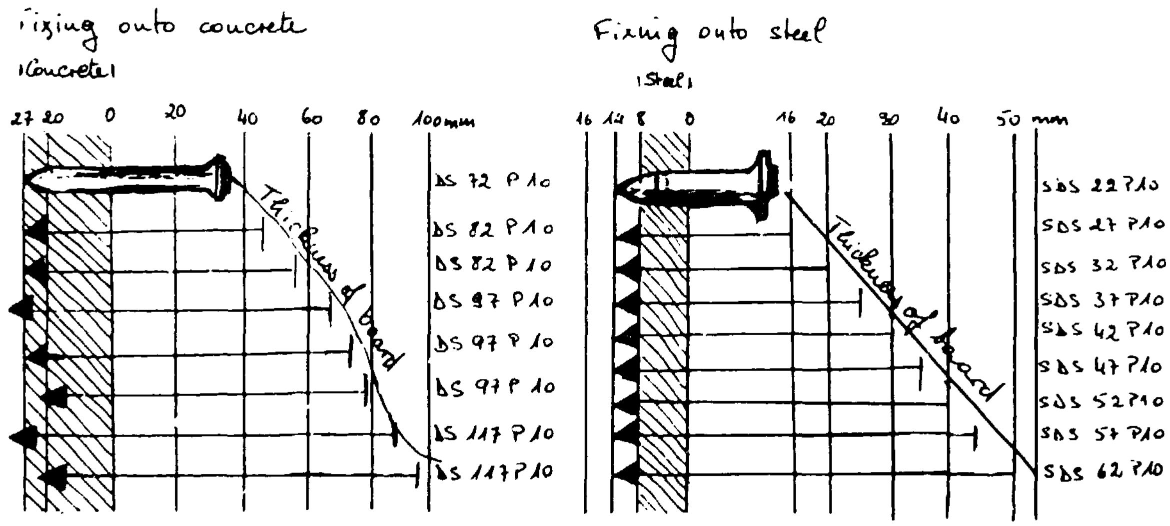


Fig. 53: Patented system of fixing the wood-wool cement board onto a concrete wall (ring with appropriate stud).

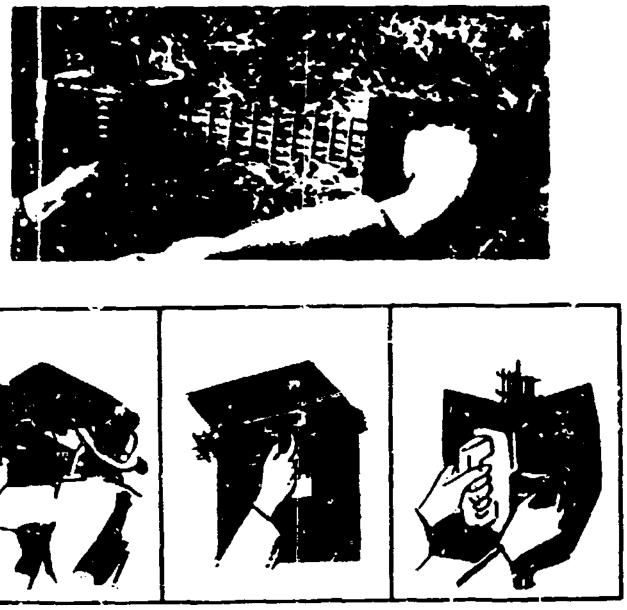


Fig. 54: Metal grating used to prevent cracking at joints

Wood-wool cement boards are often used for lost-shuttering The board remains in place after setting of the concrete which is automatically protected against fire and furthermore thermally insulated. Little iron pieces are inserted to maintain the board at the correct distance. This housing technique can be used for high rise buildings. Figures 55 to 59 show applications of wood-wood cement boards in construction

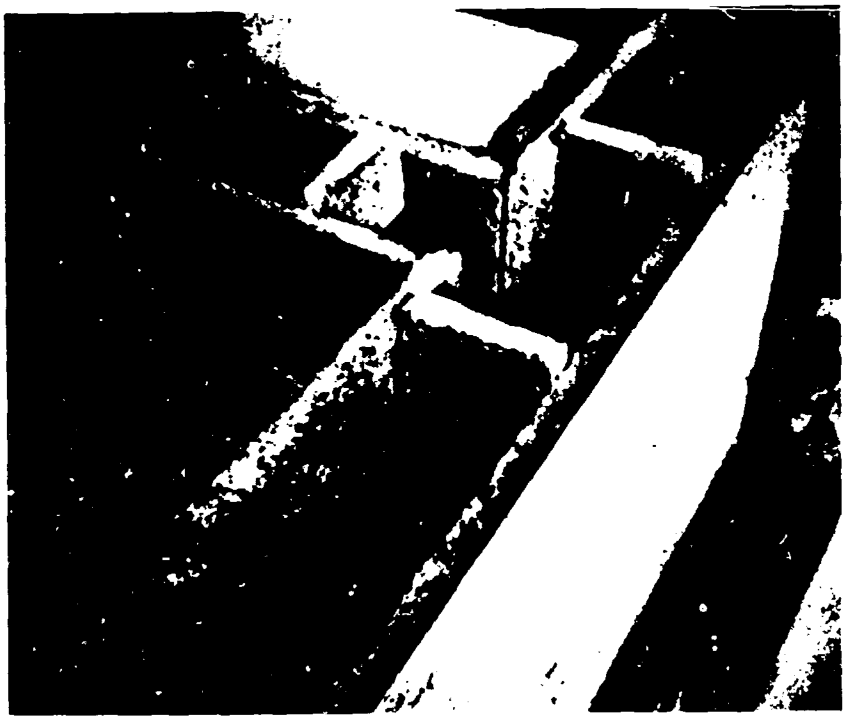


Fig. 55: Wood-wool cement board fabricated into hollow blocks.

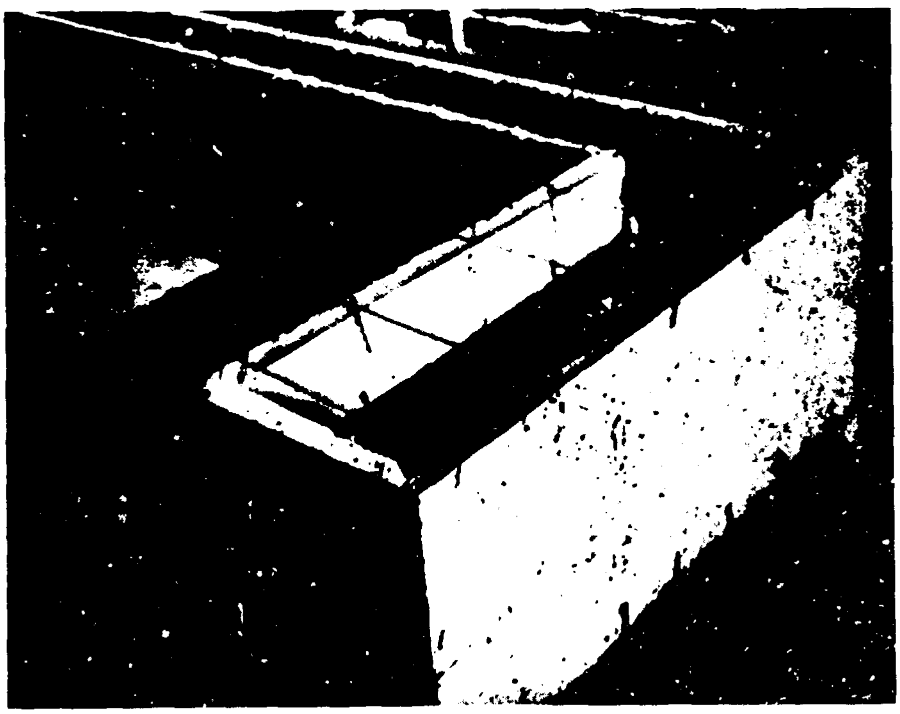


Fig. 56: Wood-wool cement board blocks showing light iron "distance pieces" to position blocks

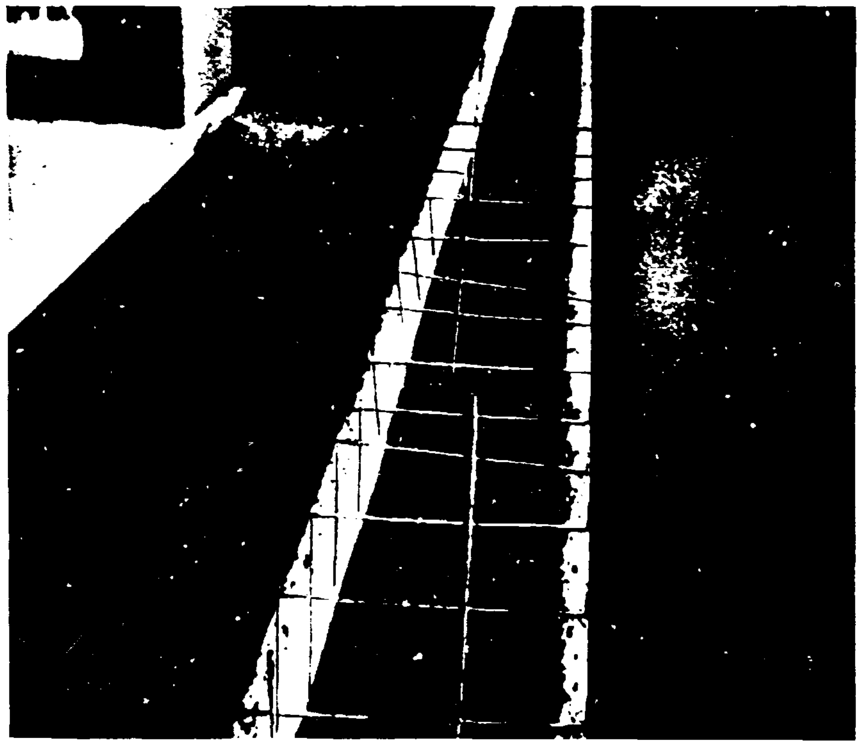


Fig. 57: Wood-wool cement board blocks with steel reinforcing rods.

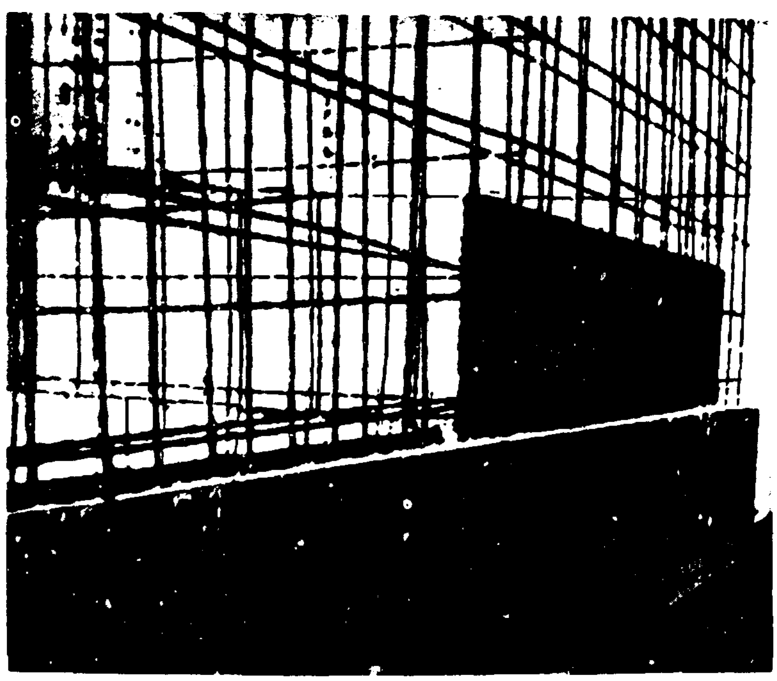


Fig. 58: Wood-wool cement boards used in shell-concrete construction - initial stages

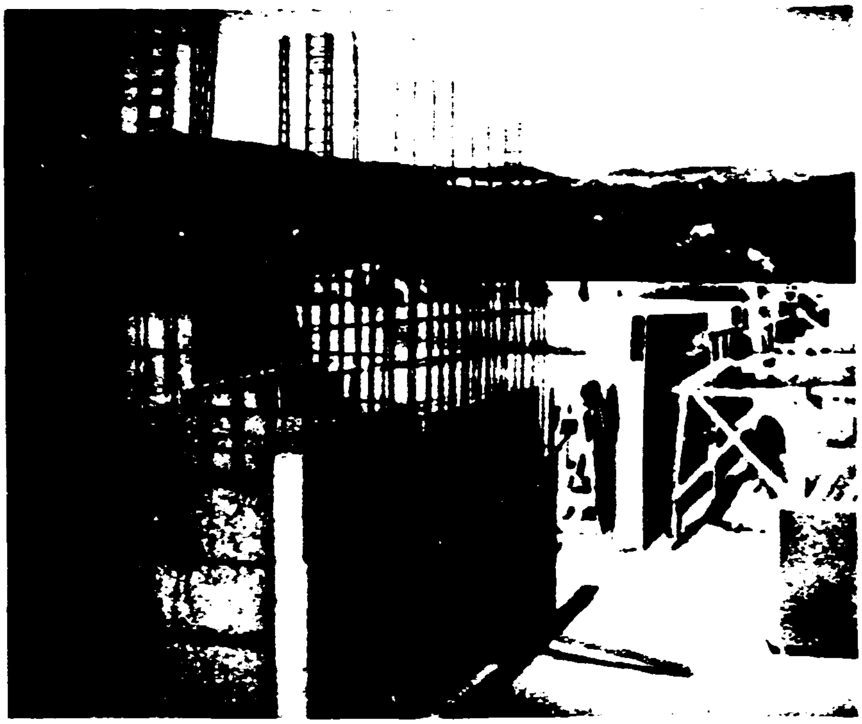


Fig. 59: Wood wool cement boards used in shell-concrete construction - initial stages - partially completed buildings.

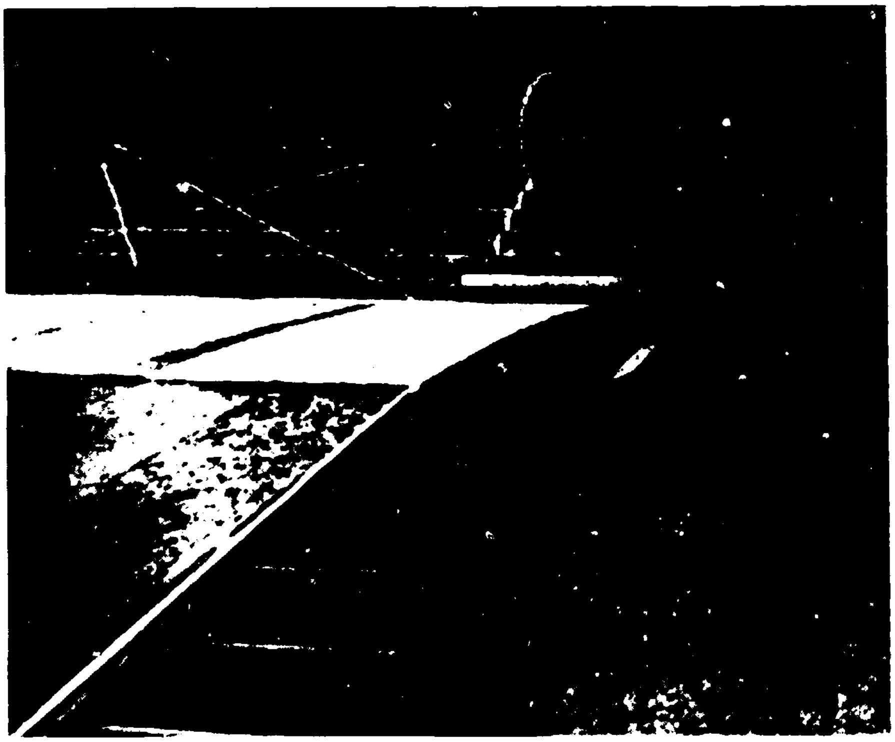


Fig. 60: Wood-wool cement boards used in roofing as an underlay to asphalt

Fig. 61: Pre-fabricated wood-wool cement sheathed panels being assembled in a low cost housing project.

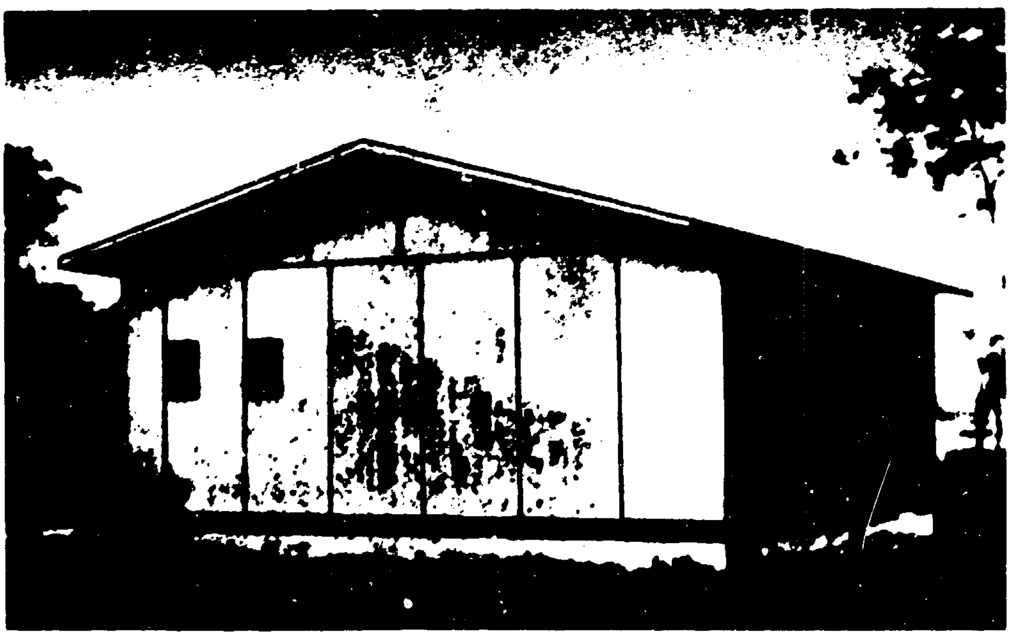


Fig. 62: Low cost housing using wood-wool cement boards

b) High density cement board:

It has similar applications to wood-wool cement boards. Since the surface is smooth and the board denser, the construction can be lighter. Figures 63 and 64 show plans for this type of construction, while figures 65 to 67 show typical examples of end uses (Its use as a noise protection barrier, exposed to the climate, is an indication of its excellent weather resistance properties.

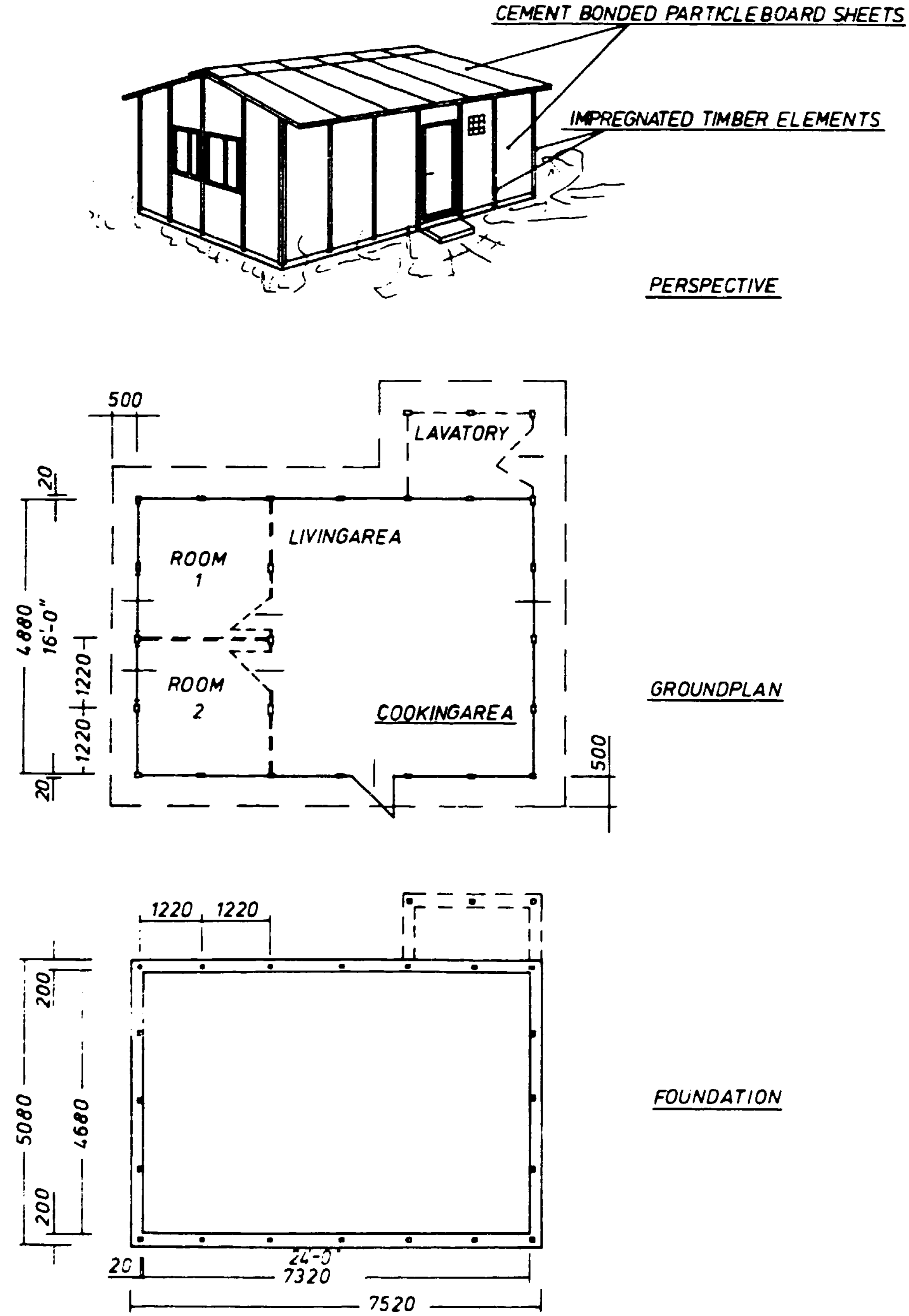
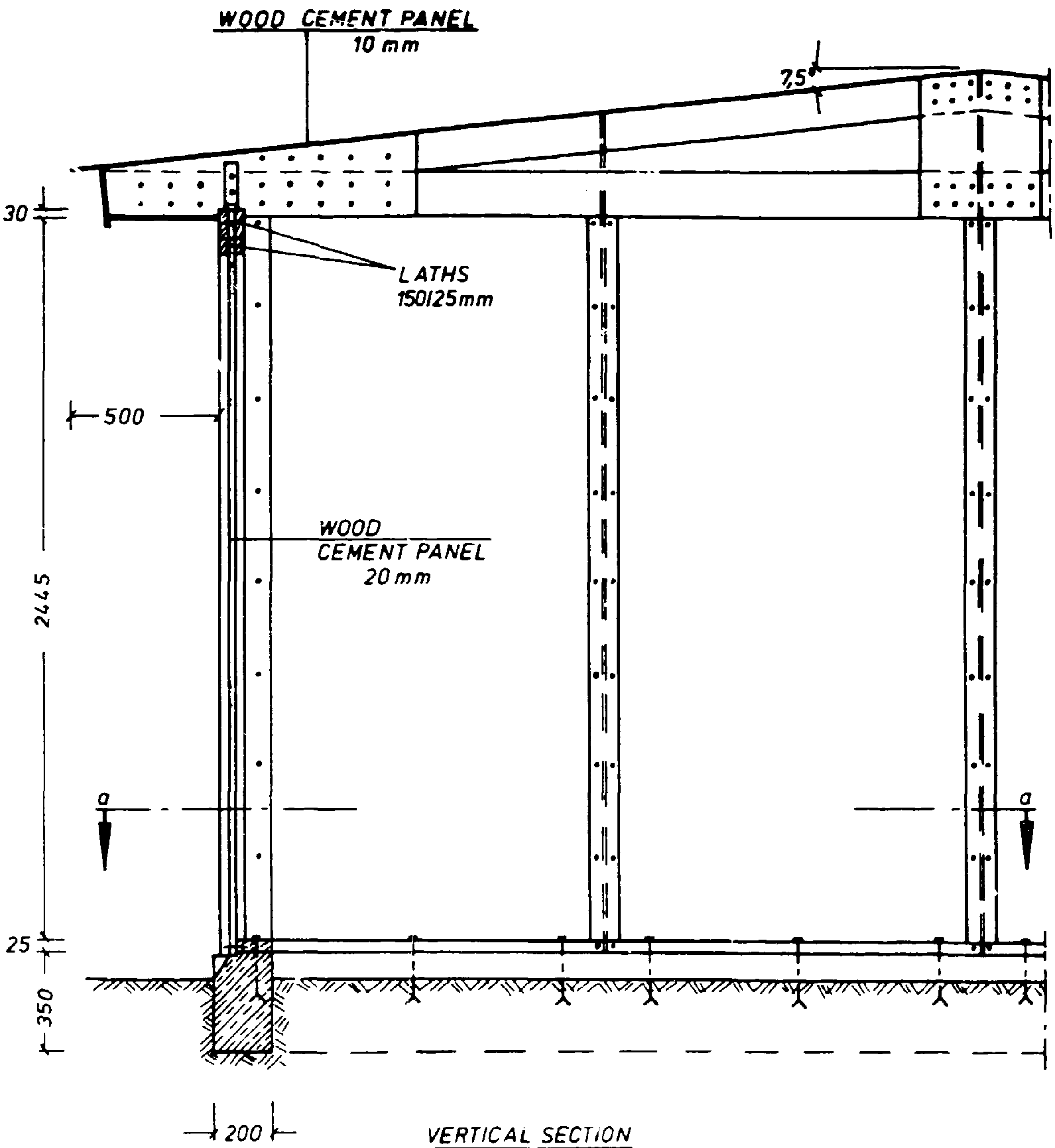


Fig. 63: Low cost single unit house using cement board.



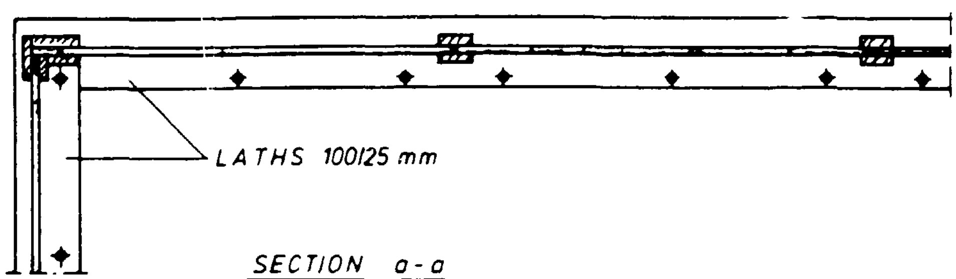


Fig. 64: Low cost single unit house using cement board: construction details

Fig. 65: Low cost house built using high density cement boards.

Fig. 66: School built using high density cement boards

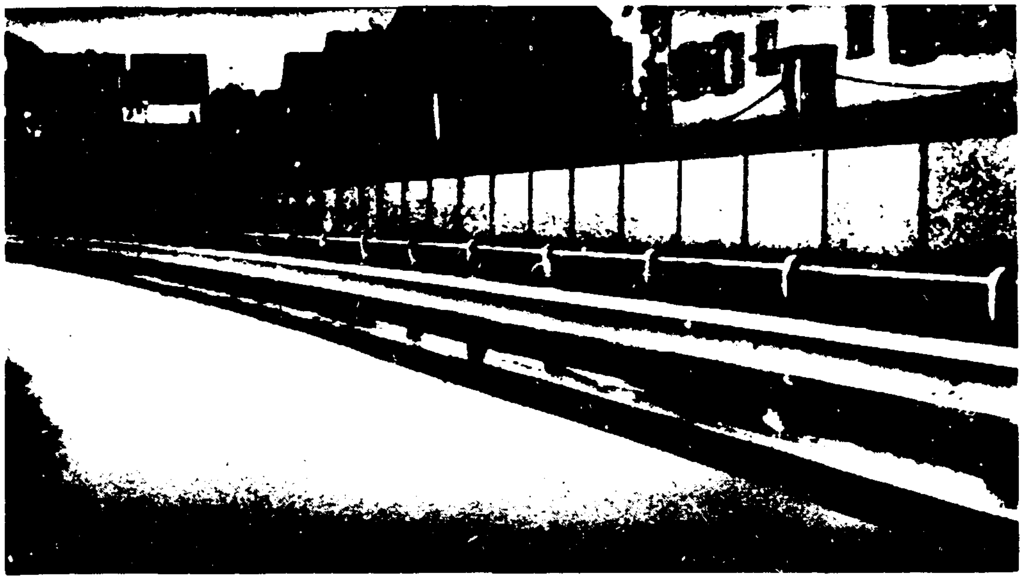


Fig. 67: High density cement boards used as a noise protection barrier.

Conclusion:

Cement boards, using mineral binder, need appropriate raw materials (wood and cement) for their manufacture.

Even without any particular treatment, their properties are very good, especially their weather resistance. Low density board can be made using equipment that is labour intensive and where economies of scale play a small role, while the heavy board requires more sophisticated machinery.

Both these types of board are very good building materials.

VI. ECONOMIC ASPECTS:

It is very difficult to compare the cost of manufacture of the different types of panel. Indeed, the minimum economic capacities differ from one product to another. Besides, the wood or the raw material needs are very different and their costs also differ from country to country. This also applies to energy, manpower, and level of mechanization. On the other hand, some processes, which are more expensive, are able to produce boards having a higher quality level.

Table V is given to serve only as general information and can only give an idea of the investments and the energy needed. Furthermore, the costs quoted have been established two or five years ago (1976-1979).

TABLE V: Comparative table of investments, raw material and energy requirements for various types of wood based panels.

	Cement board							Particle board			Plywood	Waferboard
	Low density (FAO 1979)				High density (FAO 1976)			(FAO 1976)			(FAO 1977)	(USA 1976)
	Labour Intens.		Mechanized		L.I.	Mechanized		Lab.Int.		Mech.		
Capacity m^3/day	35	65	100	180	25	50	100	20	40	150	30 - 90	95
Imported Machinery US$ 1000	368	425	933	1536	1290	3010	4400	877	1140	3510		
Total investment US$ 1000	1230	1579	2478	2834	2600	5800	8000	2000	2500	7600	2265 - 7738	
Production m^3/year (100 m^3)	9.4	17.6	27	48.6	6.7	13.5	27	5.4	10.8	40.	8 - 16	
Needs/m^3												
Wood (kg dry)	140	140	140	140	270	270	270	600	600	600	2.1(m^3)	900 kg or 2 m^3
Chemical (kg)	3.5	3.5	3.5	3.5	8	8	8	11	11	11	--	17
Water (l)	600	600	600	600	300	300	300	250	250	250	--	--
Cement or glue (kg)	260	260	260	260	730	730	730	54	54	54	55	38
Electricity (Kwh)	85	110	185	250	150	350	590	120	170	520	200	137 Partly
Oil (l)	2	2	2	2	40	40	40	80	80	80	25	6.9 wood fuel
Cost/m^3	77	66	65	60	125	122	98	138	106	90	± 300	133
Assumptions (x)												
Wood cost ($T)	125				22			22			60(m^3)	33
Cement, glue ($ T)	70				41			472			800	660

(x) For developing country, except waferbaord.

NOTE: Cost comparisons between products cannot be derived from this table.

It seems that:

- except for the plywood industry, the cost per cubic metre of board is largely dependant on the capacity of the unit.

- Wood-wool board has the lowest cost per cubic metre, but its use calls for higher thickness panels, thus diminishing the price advantage.

- the cost of the heavy cement board is about 10 percent higher than the cost of particle board, but less than the water resistant particle board.

As a final conclusion, it appears that the choice between one process or another is largely depending on:

- the level of the required mechanization, which determines the minimum capacity;
- the capacity of the unit;
- the use of the product;
- the availability of the raw materials (wood, cement, adhesive).

VII. CONCLUSIONS

It has been the intention of the author to show, through this presentation of the evolution of board manufacturing that the basic principles of board techonology remain very important, namely:

- the specific properties of the raw materials must be used intelligently to attain the requirements set by the envisaged end uses:

the evolution must be seen through real technological innovation to prevent "new process" mystification.

Thanks to the flexibility of particle board manufacture it is possible to adapt production to the necessities of any country but it is absolutely necessary not to forget that the particle board production unit selected must be the best alternative available to meet the market requirements using the available raw material.

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