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Expert Working Group Meeting
on the Production of Panels
from Agricultural Wastes

Vienna, Austria, 14 - 18 December 1970

TECHNICAL PROCESSES FOR THE PRODUCTION OF WOOD-WOOL/CEMENT BOARDS AND THEIR ADAPTION FOR THE UTILIZATION OF AGRICULTURAL WASTES 1/

by

W. Sandermann
Federal Research Organization for Forestry and Forest Products
Reinbek/Hamburg
and
Chair of Wood Technology at the University of Hamburg

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Corrigendum

Page 6, Table 1

Change heading of fourth column to read as follows:

weight of board 1)2)
middle value
kg/m2

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1. Short description of the production processes

Wood-wool boards are manufactured from wood-wool and a mineral binder, e.g cement, magnesite or gypsum (1). The first product on the market was bound with magnesite, a mixture of magnesium chloride and magnesium oxide ("sorel-cement") (2, 5, 6). It was manufactured in 1921 by the Oesterreichisch-Amerikanische Magnesit A.G. in Rathenthein. These "Heraklith" boards were produced in a rather complicated way, by sawing them from blocks. Later on, processes and equipment were improved considerably and cement became the predominant binder (1, 2, 7). As a raw material, spruce was the preferred wood. Besides this, pine, poplar and willow were used. But not all woods were suitable for this purpose, because the content of sugar, tannin and other extractives showed itself to be a limiting factor (4, 8). These are of the order of 0.15 per cent. Through these substances the setting of the cement was retarded or even inhibited. In such cases, no useful boards could be produced.

Plants for production of wood-wool boards are more or less mechanised (7). In the first stage of the production line, the logs have to be cut into pieces 50 cm long by normal circular and band saws or automatic cross-cut saws. From the rolls wood-wool is planed in wood-wool machines of the horizontal or vertical type. The dimensions of the wood threads are standardised in the Federal Republic of Germany by DIN 4077. For wood-wool board the normal width is 4 to 5 mm and the length 500 mm. The moisture content should not exceed 20%. With a new type of wood-wool machine, manufactured by FAMA, Bolsano, Italy, and probably other firms elsewhere too, waste wood and slabs from saw mills can be planed.

Wood-wool type shavings from agricultural wastes may be manufactured by chopping the material (straw, bagasse, etc.) and then by reducing the chopped material to fine pieces. Machinery for this purpose is manufactured by B.M. Schneider, Obersdorf/Siegen, Federal Republic of Germany, and also by other firms.

From among the different production processes, a few may be mentioned. The machinery of the firm SATTLER, Kulmbach, is probably the smallest and cheapest equipment for the manufacture of wood-wool boards. The system of KARL SCHNEIDER, Zahl/Main, works half automatically, and consists of a large mixer with a dipping tank for the mineralisation of the wood-wool, the feeding unit for cement and the mixer drum. The blended mixture is discharged continously into a weighing machine. By means of a conveyor belt the material is automatically transported to the filling station, where the moulds are filled to a high level of uniformity. A pile of 30 filled moulds is transferred mechanically to a press with four vertical sides to each platten, where the pile is compressed for 1 ½ minutes and clamped together. After the removal from the press, the pile is stored for 15 to 20 hours and the boards are separated from the moulds. The capacity of the system is nearly 250 slabs (2000 x 500 x 25 mm) in one hour.

In the procedure of FRIEDRICH E. HIRSCH, 8081 Türkenfeld/Obb., the production line consists of the wood-wool lift-conveyor, the mixer, with inlets for the mineralization solution and the cement, the distributing tools, pressure rolls for the mats, the cut-off saw, stacking platform and the hydraulic press with two or four vertical sides to each platten. The capacity of this machine for boards 15 to 75 mm thick is 2 to 6 slabs/min. The factory manufacturing the machines recommends this type for developing countries, because the price is low and the mechanisation is not too complicated.

The system of GEBRÜDER CANALI, Speyer/Rhein, is fully automated and is well known in many countries (9, 10). The manufacturing line consists of the following stages: automatic conveyor for the wood-wool, dipping tank for mineralisation, wringer for pressing out superfluous solution, continuous mixer for adding cement in exact doses, distributing station for the forming of the mat, cut-off saw, stacking platform and hydraulic press. The capacity is 2 to 5 boards per min. with the dimensions 2,000 x 500 mm and thicknesses of 15 to 75 mm. Slabs with one, two or three layers can be manufactured and 2 or 4 edges can be pressed. For the whole plant 4 to 5 workers are needed as manpower, and 77 kW in total energy. Two wood-wool machines are needed for an output of 1,500 boards (2000 x 50 x 25 mm). The power consumption of these two machines is 37 kW. For one panel with the dimensions 1,500 x 500 x 25 mm, the following raw materials are required: 5 - 6 kg cement and 3.5 kg wood-wool. Besides this, mineralisation chemical costing US $0,01 is needed.

The fully automated machine of G.J. VAN ELTEN, Voorthuizen/Holland, is probably the most widely distributed system (11, 12). The stages of manufacture are similar to those mentioned previously. The wood-wool, weighed in an automatic unit, is impregnated in the mineralisation tank with diluted calcium chloride or magnesium chloride (3°Bé). After this, the surplus solution is pressed out by rubber rollers. The wood-wool so prepared is blended with cement in a mixer working continuously. By means of a dosing belt weigher, continously-moving moulds are filled with the mixture. The moulds pass through the pre-moulder, the side pressing discs, and the separating saw. The individual moulds are piled. Then the piles are pressed in the piling press. A fork lift truck takes over the pile and puts a second onto it to form a double pile of 50 moulds. This double pile is pressed by concrete weights for 25 hours. By that time the boards are hardened. By an edge-stressing saw the longitudinal edges of the slabs are cut off to a length of 2,000 mm. Then the trade mark is printed on the board.

All boards, manufactured according to the above mentioned processes, are porous and have a specific gravity of 0.36 to 0.57.

By the "Century-Board" -process of A. ELMENDORF, a non-porous cement-bound board is manufactured, which has a specific gravity of 1,05 to 1,20 (14-16). After the installation of a pilot plant in Mountain View, California, The Elmendorf Research Inc., Palo Alto, California, gave a license to Mitsui Lumber Co., Tokyo (13). The "Century -Board" is a 3-ply panel with the strands of the outer plies approximately parallel to the long edges of the panel. The ratio of cement to wood is 2,100 lbs cement to 800 lbs wood by weight.[1/] As raw material, roundwood, slabs and wood trim from saw mills may be used. It is cut into flakes, which are converted to strands. In a mixing machine dry portland cement is added. In this operation, the cement must be retained on the strand. Therefore, the percentage of water in the wood is of high importance. The cement-coated strands form a continuous mat by an operation of air felting, on a succession of metal caul plates in end-to-end contact. After compression of the mat by rollers, the cauls, each with a mat, are stacked and pressed at pressures as high as 200 psi, to achieve the desired density of 1. to 1.2. The mats are kept under pressure until the cement has set. For this, 12 to 16 hours are needed. The board can be force-dried with warm air 24 hours after forming. But preferably the slabs are air-dried by placing them edgewise on a rack for three to five days. The dried boards are trimmed to the desired size with carbide-tipped saws (14). Until now only one firm, the Mitsui Lumber Company, Tokyo, manufactures the "Embedded Fiber Board" (Century Board). The strands of wood are 1 ½ to 2 inches long, 1/32 to 3/16 inches wide and 0.01inches thick. The three-layer board is 3 feet wide, 6 to 9 feet long and ½ inch thick.

1/ Two volumes cement to one volume wood.

Most of the production is factory-painted for building exteriors. The panel strength in resistence to bending and stiffness is about the same as that of douglas fir plywood. The production in the Mitsui mill is about one million square feet monthly.

In the Union of Soviet Socialist Republics, according to the literature available, two products are known: FIBROLIT and ARBORIT (17-23). Fibrolit is made of wood shavings or wood-wool, with a cement made from a mineral sludge, which is an industrial by-product. Arborit is produced from wood particles, calcium chloride and cement. However, other formulas have been reported too. According to Oshogin, 0.4 m^3 wood particles, freed from sawdust, are soaked for 4 to 6 min. in water and then mixed for 4 to 5 min. with 0.18 t Portland cement and 0.72 kg water-glass (sodium silicate). The mixtures in moulds are pressed and the surplus water extracted by a direct current (30 V, 15 A/m^2). The direction of the current changes every three to four minutes. The specific gravity of the boards is 0.6 to 0.7, their dimensions are 3,000 x 1,200 x 20 mm (19). The weight of an Arborit board is 468 kg. It seems that in the Union of Soviet Socialist Republics Arborit is a building material appreciated by architects. The first plant, in Kasackstan, produced 40,000 m^2 per year of Arborit from coniferous wood and Portland cement. According to a newer Russian patent, the wood particles are first mixed with cement, heated to 150 to 250°C, then a blend of the remaining cement, calcium chloride and water is heated to 80° and added to the hot mixture (23).

The raw material of the DURISOL-process (DURISOL A.G. FUR LEICHTBAUSTOFFE, Dietikon, Switzerland) consists of softwood shavings (3 to 30 mm), bought from saw mills (24-27). They are freed from saw mill dust, mineralised, mixed with cement and moulded under pressure into building boards, hollow building blocks, roof-decks, roofing tiles etc. Today, more than 20 factories operate under licences from Durisol A.G. This firm also manufactures roofing boards of 4 to 7 m length and exterior boards (2 to 8 m) with rough-cast surfaces. These are constructed with inlaid iron reinforcements. These large boards are especially used for industrial buildings and storehouses.

The hollow building block permits very fast building and is a preferred building material for prefabricated houses (26). For this purpose, other products share the market with Durisol, e.g. "ISOSPAN" (Alpina Holzindustrie, Freilassing) and "EUROSPAN" (Holzbetonbaustoffe, Kranebitter K.G., Pfaffenhofen, Tirol, Austria). Similar building blocks ("woody concrete") are also utilised in the Union of Soviet Socialist Republics, e.g. for the construction of one- to two- storey houses.

2. Brief description of the product (wood-wool/cement board) and its uses with specific comparisons of its advantages and limitations with respect to other wood-based raw materials (and building materials)

Wood-wool board is a building material with exceptionally favourable properties (6,28,29). In order to facilitate the application of this slab, the properties have been standardized in the Federal Republic of Germany with the specification DIN 1101, in Austria with B 3465 and in England with British Standard 1105 (Table 1). These standards fix first of all the dimensions of the slabs, the weight, and other properties. In the Federal Republic of Germany boards, which fulfill the quality conditions are stamped with the DIN-mark and the trade-mark of the factory. Usually, the results of tests on the actual panels are a great deal better then those claimed by the standards. The absorption of water by wood-wool boards is lower than that of wood. Furthermore, the absorption of wood-wool boards depends on the mineral binder. Cement-bound board is therefore more resistant to water than that bound with magnesite or gypsum. According to Kollmann, for 75 per cent humidity the equilibrium moisture on desorption for wood wool board (u) is 6.5 per cent, but for untreated pine or spruce it is 13 per cent (30).

The thermal conductivity of wood-wool board depends on its density. It is - for the same values of density - a little lower than that of wood. According to DIN 1101, the thermal conductivity of wood-wool boards should be 0.08 kcal/mh°C. The thermal conductivity of fibre boards of the same density is lower.

The high absorption of sound of wood-wool boards is one of the most valuable properties of these slabs. This is the reason why wood-wool boards are used in concert halls, radio and broadcasting studios, cinemas, churches etc.

The elasticity and bonding strength of wood-wool boards are interesting, because these properties influence the behaviour of the boards in building and the risks involved in transport and workability (Table 1, Table 2).

Wood-wool boards are not inflammable and are durable against fungi and insect attacks (31). These important advantages favour this panel as a building material. In humid and hot areas, e.g. the tropics, mineral-bound light-weight wood-wool boards will not be destroyed in conditions under which non-preserved wood would decay.

Table 1. Dimensions, weights and properties of wood-wool board according to standard DIN 1101 (28)

Thickness mm	Width mm	Length mm	Weight of board 1)2) middle value kg/m^3		Density 2)		Bending strength middle value kg/cm^2	Compressibility % of thickness
permissible tolerance								
+3 -2	+5 -5	+5 -10	mono-layer	multi-layer	multi-layer	mono-layer	tolerance: -10%	tolerance: +10%
15			8.5	-	570	-	17	-
25			11.5	-	460	-	10	15
35			14.5	-	415	-	7	18
50	500	2000	19.5	-	390	-	5	
75			28	36	375	480	4	20
100			36	44	360	440	4	

The thermal conductivity at 20°C in kcal/mh °C is 0,08

1) Boards are still suitable according to this standard, if the middle value has been exceeded by 10 per cent

2) The weights of the boards may be exceeded by a maximum of 20 per cent, but they may not be lower than the figures indicated.

As mentioned in Chapter 1, "Embedded Fibre Board" (Century-Board) by Elmendorf is non-porous. Therefore, some properties are different from those of porous wood-wool board. Thus, the specific gravity of Century Board is 1.05 to 1.20. Other properties may be compared with those of plywood, gypsum board and insulation board (Table 2).

Table 2. Comparison of "Embedded fibre board" and other panels
Modulus of elasticity and modulus of rupture

Panels	Modulus of elasticity psi		Modulus of rupture psi	
	strong way	weak way	strong way	weak way
½" Embedded fibre board	950,000	300,000	3,300	2,000
½" 5-ply-Douglas fir plywood	920,000	400,000	6,850	5,500
½" Gypsum board sheathing	370,000	135,000	860	340
½" Insulation board	45,000	37,000	340	290

Table 3. Comparison of "Embedded fibre board" and other panels
Expansion and water absorption after 24 hrs. immersion in water (14-16)

			Expansion, %		
	spec. gravity	water abs. %	length	width	thickness
½" Embedded fibre board	1.18	21.4	0.14	0.20	3.11
3/8" 3-ply Douglas fir plywood	0.66	24.0	0.18	0.38	4.63
5/8" 5-ply Douglas fir plywood	0.51	40.0	0.24	0.40	4.23

The nailability as well as the resistance of Century board against fire and termites are said to be excellent. Most convincing was the weather resistance test. Such tests have been in progress for about 15 years with different specimens. An unpainted board, having a cement to wood ratio of about 3 : 1, after ten years in the weather, showed a noticeable roughening of the wood particles of the surface, similar to the behaviour of wood. But there was no real disintegration of the board. The painted Century-boards showed, after 8 years of normal weathering, no disintegration nor surface pitting. So, Century-board may be used as an exterior building material. One reason for the success of wood wool boards is the easy workability. They can be sawn, bored and nailed.

Some properties of the hardened Durisol material are:

specific gravity	0.55 - 0.60
bending strength	9 - 12 kg/cm^2
compression strength	12 - 23 kg/cm^2
modulus of elasticity	about 3000 kg/cm^2
shrinking	up to 1 % with fresh material
	0.4 % with stored material

Other properties are similar to those of cement bound wood-wool boards.

The use of cement bound wood-wool boards, building blocks and elements depends on the above-mentioned properties. All cement bound products are used in house building, e.g. for house walls, exterior as well as interior. Boards may be fastened with galvanized nails on wooden frames. A new type is the "Coated concrete wall" ("Mantelbeton") (32). This is a three-layer wall consisting of a central concrete core and wood-wool boards on both sides. During the building the concrete is poured in the space between the two boards. In this way, appartment houses can be constructed in a very simple way. Another cheap and simple method of wall construction can be practiced with Durisol hollow building blocks. They are put together and concrete is poured as a core into the cavities of the blocks. Durisol exterior boards 2 x 8 m are an ideal building material for the walls of industrial buildings, store-houses etc. The building elements are fastened to iron frames. Wood-wool boards can also be used for roofing, ceilings, flooring, building of garages, pavillions etc. If advisable, the surface may be plastered or painted.

Because of the high insulation properties of cement bound wood-wool boards, they are used in cold areas against the cold and in the tropics against the heat. For example, in India, factories, hospitals, airfield buildings, schools etc. have roofs constructed with boards 10 cm thick. In this way the radiation heat of the sun is absorbed and the climatising units operate more economically. This favourable effect was achieved in a building utilising Durisol boards in Morocco, where 40 per cent of the energy consumed for climatising was saved.

3. <u>Enumeration of the potential raw materials of agricultural origin and other non-wood ligno-cellulosic materials, that can be used in the processes enumerated above</u>

The role of wood-wool or wood shavings in cement bound boards and building blocks is to lower the specific gravity and to give strength to the material. Chemically, wood is lignocellulose. But, besides wood, other fibrous plant material too is of lignocellulosic nature (33, 34). Therefore it is obvious that such plant material could be used instead of wood for cement bound boards. Such material exists in abundant quantities in the form of agricultural residues, e.g.

wheat-, rye- and oat-straw
rice straw
cotton stalks
corn stalks
sugar-cane bagasse
flax
hemp
bamboo
sisal
rice hulls
kenaf fibre
corn cobs
quinine stems
peanut shells
esparto grass
coconut fibres
date palm fibres, etc.

Some of these raw materials may be of interest for the production of cement bound boards, others not. In general, the use of agricultural residues is connected with technical and economic difficulties. First of all, the waste material has to be collected during the harvest, which means that large amounts of perishable material have to be stored for the whole year. Another disadvantage is the fact that the waste material is often produced in small scattered areas, so that the collection and transport is not economic. On the other hand, in areas where the cultivation of certain crops is dominant, agricultural residue can be interesting for the manufacture of cement bound boards. Therefore, the above enumerated waste materials shall be examined with regard to their usefulness.

Cereal straw (wheat, rye, oat).

The main straw-producing areas, where board production could be practicable, are European countries (France, Germany, Greece, Holland, Hungary, Italy, Spain, Union of Soviet Socialist Republics) and North America (United States and Canada). The world production of straw is tremendous: 600 million tons/year. From this amount 350 million tons are wheat straw. Western Europe produces 80 million tons annually.

Rice straw

Rice straw is mainly produced in Southern Europe, United Arab Republic, South America, Eastern Asia (China, Japan) and South-East Asia (Burma, India, Indochina, Indonesia, Thailand). For every ton of rice, about 1.5 tons of rice straw is produced as a by-product. In South-East Asia, the harvest may be 80 million tons of rice straw. Mostly it is used for agricultural purposes, e.g. cattle fodder.

Rice hulls

It seems that this by-product of rice cultivation is available only over a small area.

Corn stalks and corn cobs

These residues may be a valuable raw material in the United States, Canada and some Latin American and European countries.

Flax

All flax in the world comes from the plant Linum usitatissimum L. of which several species are known. It is produced everywhere in the northern hemisphere, in the girdle from North Africa, Asia Minor to India and also in South America and Australia. In Europe and the Union of Soviet Socialist Republics the fibres are the main product, but in tropical and semi-tropical countries it is the linseed oil. The production of different countries is summarised in Table 4.

Hemp

This fibre plant (Cannabis sativa L.) grows in the tropics as well as in temperate zones. Usually it is cultivated in areas with a low income level. Besides fibres, oil from the seed is produced. A problematic by-product is the narcotic haschisch or marijuana. The real raw material for boards is - similar to flax - the non-fibrous part. The world production of hemp waste is summarised in Table 5.

Table 4. World production of linseed oil and flax 1964/65 (35)

	1000 metric tons			
	Linseed		Flax	
Brasil	54			
Mexico	6			
Southeastern South America	886			
Southwestern South America	3			
Latin America		949		
East Africa	54		11.1	
North Africa	30			
Africa		84		11.1
East Asia			2.4	
Japan	2		4.6	
Near East			17	
South Asia	478			
Southwest Asia	7			
Asia		487		24
Europe (includes Turkey)		243		285.5
North America		620		
Pacific Area		106		0.2
Union of Soviet Socialist Republics		445		337
World		2,934		657

Table 5. Production of hemp waste 1964/65 (35)

Europe + Turkey (Turkey 36 in 1,000 metric tons)		528
South Asia	275	
East Asia	32	
Japan	22	
Asia		329
Total		857

These figures are derived from the assumption that 1 ton of fibres yields 3.8 tons of hemp waste.

Cotton stalks

Most species of cotton are annual with plants of 1 to 2.5 m in height but some are perennial. Cotton can be cultivated in areas with an average annual temperature of 20 to 30°C. The production of cotton stalks is given in Table 6. It should be noted, however, that in many cotton-producing countries legislation exists which obliges the farmers to burn the cotton stalks after the harvest so as to reduce the likelihood of insect attacks on the next crop. In these countries raw material would not be available.

Sugar-cane bagasse

This material is the fibrous by-product of sugar manufacture from sugar cane (Saccharum officinarum L.). This important "grass" grows in the tropics and subtropics. The stem of the plant is nearly 5 cm thick and up to 8 m high. Inside, the plant is solid and not hollow like some other grasses. Fresh sugar cane contains 75 per cent water, 13 per cent sugar, 11 per cent fibres, 1 per cent other substances. The surface of the stem is coated with wax. The ash content of bagasse is 1,7 to 2.5 per cent. The chemical composition of the cell wall is similar to that of wood: cellulose 46 per cent, lignin 23 per cent, hemicelluloses 26 per cent, rest 5 per cent. Anatomically bagasse contains 40 - 55 per cent bark, 15 - 35 per cent sclerenchym and 20 - 35 per cent parenchym. The production of bagasse is summarised in Table 7.

The sugar cane is brought to the mill with a water content of about 70 per cent. It is crushed, squeezed and washed, to remove the sugar juice. The residual bagasse contains 50 per cent water and 1 to 2 per cent sugar. The bulk of the bagasse (approximately 65 per cent to 75 per cent) is used as fuel. So, only a part of the bagasse is available for the manufacture of boards and pulp. Fresh bagasse has a calorific value of 1600 to 1700 kcal/kg. If it is substituted by any other fuel more of this valuable by-product can be used. But it has to be mentioned that the pulp industry is a strong rival for its eventual use.

Bamboo

Bamboo is a grass with several genera and species (170 in India and 70 in America). From the perennial roots, the stem grows to its full size (as high as 40 m with maximum diameters of 30 cm) in 7 to 10 years.

Table 6. Disposal of cotton stalks 1964/65, in 1000 metric tons (36)

Europe and Turkey		1,378
Union of Soviet Socialist Republics		4,950
North America		—
Brazil	1,623	
Caribbean Islands	3	
Central America	820	
Mexico	1,521	
Northern South America	242	
Southeastern South America	413	
Southwestern South America	407	
Latin America		5,020
Eastern Africa	916	
North Africa	1,405	
Southern Africa	50	
West Africa	385	
Africa		2,756
Arabian Peninsula	22	
Eastern Asia	3	
Mediterranean area	528	
Pacific area	17	
South Asia	3,721	
Southeast Asia, continental	124	
Southeast Asia, insular	—	
Southwestern Asia	437	
Asia and Pacific area		4,852
Total:		20,045

All figures are derived from the assumption that 1 ton of fibres corresponds to 2.75 tons of cotton stalks.

Table 7. Disposal of sugar cane bagasse in 1965/66 (37)
in 1,000 mt. in a dried state

Brasil	5,822	
Caribbean Islands	8,615	
Central America	752	
Mexico	2,522	
Northern South America	1,657	
Southeastern South America	1,630	
Southwestern South America	1,108	
Latin America		22,106
East Asia	1,465	
Japan	104	
Pacific area	2,759	
South Asia	5,196	
Southeast Asia, continental	408	
Southeast Asia, insular	2,612	
Southwest Asia	30	
Asia and Pacific Area		12,574
Eastern Africa	2,111	
Northern Africa	439	
Southern Africa	1,225	
Western Africa	169	
Africa		3,944
Europe		98
United States (incl. Hawaii)		2,136
Total:		40,318

All figures are derived from the assumption that 1 ton of sugar corresponds to 1.2 tons of bagasse, in a dried state

In India, the annual growth of bamboo is about 2 t/ha (air dried). In other countries the potential annual yield is much higher (e.g. Pakistan, 7 t/ha), while in others it is still very low (e.g. in the Republic of Viet-Nam it is only 0.2 t). Bamboo is a valuable traditional material for house building. Besides this, in some countries, it is the sole indigenous supplier of long fibres for the paper industry. Therefore it may be doubtful whether bamboo will be available as a raw material for cement bound boards. The bamboo resources in Asia and the Far East are summarized in Table 8.

Other agricultural residues, such as banana stalks, coconut fibres, peanut shells, etc. may be of more local importance.

This survey enumerates agricultural residues which could be used as a raw material for cement bound boards and building blocks. Whether they are actually used for this purpose depends on different presumptions, such as the suitability of the waste fibre material, the price of the residue and finally on the processing and market possibilities. Countries with no or insufficient wood resources, but with a high production of bagasse and other wastes, should be able to produce building material on this base. These are Cuba, India and the United Arab Republic. The manufacture of such building boards and blocks is a potential industry for the low income level Northeast region of Brasil where sugar cane is the predominant crop.

It is very difficult to quote definite prices for the waste materials, which could serve as a comparison for wood prices, because conditions vary in different areas.

Experience with cement bound boards and building blocks from agricultural residues

The manufacture of cement bound boards and building blocks is a rather young industry. In spite of the fact that the first wood-wool board, bound with cement, was on the market in 1928, the real development of this product only began after the last war. Naturally, wood became the most favoured raw material. But, occasionally, agricultural waste material was used or tested for the same purpose (Table 9).

Table 8. Bamboo resources in Asia and the Far East[1] (38)

Country	Year to which figures for all areas are reflected	In use ha	Total area in 1,000 ha	Potential annual yield air dried tons/ha	Recorded harvest 1,000 metric tons	Potential removals from area in use 1,000 metric tons	Potential removals from all areas 1,000 metric tons
1. Continental South-East Asia							
Burma	1958	-	9,000	5	0.3	-	45,000
Cambodia	1958	-	200	3	-	-	600
Malaysia	1958	-	-	2.4	-	-	-
Republic of Viet-Nam	1958	60	-	0.2	8.7	12	-
Thailand	1958	-	-	-	17.5	-	-
2. Insular South-East Asia							
Indonesia	1958	35	-	-	1.424	-	-
North Borneo	1958	-	-	-	1.1	-	-
Philippines	1958	-	-	-	3.6	-	-
Western New Guinea	1958	-	-	4.1	-	-	-
3. South East Asia							
India	1955	-	-	3	-	-	1,953
Pakistan	1958	-	100	7	239.4	-	700
4. East Asia							
Japan	1957	52	174	6.6	341	-	1,150
Republic of China	1958	-	114	5	35.3	-	570
Republic of Korea	1957	-	3	3	1.7	-	9

[1] Not including West Asia, Mainland China and Oceania, for which details are not available.

Table 9. Processes for the manufacture of cement bound boards from agricultural wastes and other residues

Name	Year	Waste material and process	Literature
T. Nishi	1925	rice husks + lime + cement	44
A. Hirschfeld	1929	bagasse, reeds, esparto grass, banana fibre, cork, seaweed Heat, + glue, + cement, + pressure	45
	1937	peat, straw, etc.	46
C. G. Britton	1937	bagasse + glue + magnesite	43
K. E. Blaustein		rye straw + lime + clay + cement	47
		hemp, flax + inorganic additive + cement. sample density 0,750	48
		rice hulls, for building blocks	49
P. Anft	1943	straw, peat, reeds, cork, spruce needles, heather, hemp + lime + cement	42
Factory in Holzminden	1948	peat and fir cones + sawdust milled, mineralized + cement	50
J. F. Beaudet	1952	bagasse, grass, straw, soaked in solution of dimethyurea + urea, then + magnesite	51
T. Sakai	1954	board with 3 layers. Middle layer: bamboo fibres + inorg. fibres + cement	52
St. Arkai, A. Füredi and F. Takacs	1957	Waste of Artemisia/Ambrosia + Calcium chloride + cement	53
J. L. Angeles	1958	reeds + lime + cement	54
A. C. Miller and H. Fishman	1958	bagasse + lime + Calcium chloride + (cement + pozzolan)	55
G. P. Bourlin	1967	bagasse + Calcium chloride + silicate + cement	56
G. P. Bourlin Versicrete Industries	1966	bagasse, coconut fibre etc, extraction of inhibitor with sodium hydroxyde, drying, + cement	57
A. E. Chittenden and L. J. Flaws	1968	rice hulls + cement building bricks	58
	1970	new development in Cuba: bagasse + cement = new building product for the future	59
Gebr. Canali, Speyer	1970	bagasse + pre-treatment + cement product = "VELOX Bagasse Board"	60

In **Sweden** straw boards ("Stramit") were manufactured without binder, but with two outer layers of kraft paper (39-41). After the last war, similar boards with water-glass were produced in Germany. The first cement bound board from straw is said to have been manufactured in the Baltic. Nothing is known about the quality of this product. More recent experiments have proved that straw in its natural state will not yield good boards, because straw has a surface layer of wax which inhibits the adhesion of cement. Therefore straw has to be reduced to finer particles or pieces. These, after mineralization, mixing with cement and moulding under pressure give boards of a sufficiently good quality. However, the opinion of different firms on this point is contradictory. It seems that some factories have succeeded in processing boards of a good quality from wheat and rice straw, whereas others did not. According to a patent held by P. Anft, rice straw has to be mineralised with lime before it is mixed with cement (42).

A raw material of high interest is bagasse. In 1937, J. G. Britton proposed in a patent (43), to mix the components according to the following formula:

	ounces
Water	20
Bagasse	5
Magnesium oxide	8
Magnesium chloride	8
Glue	1/8

Then the mixture is whipped and enriched with unpurified air, thus largely increasing its volume. After pouring into suitable moulds, panels and tiles are produced. MILLER and FISHMAN proposed adding to the prepared bagasse first lime, then possolan and finally the cement. The removal of pith from the bagasse, e.g. by screening or air classifying, increases the strength of the boards. A light-weight concrete roof slab can be made in the following way. In a mixer of 14 cu.ft. the materials mentioned hereunder are mixed:

Portland cement	4750 lbs
Calcium chloride	470 lbs
Fresh, shredded bagasse	2375 lbs, dry basis
Slaked lime	3780 lbs
Possolar	1890 lbs
Water, to give consistency	

The mixture is transported to a feed hopper and from there to the tamping and moulding station. The moulds containing the products are heated in a curing room for 14 hours at 120 to 150°F and may be sawn to the desired sizes (55).

Some factories have reported, that experiments with bagasse gave disappointing results, because the cement did not bind. It is supposed that the bagasse, in such cases, still contained small amounts of sugar, which is a strong inhibitor of cement setting. Therefore, the bagasse should be free from sugar. This can be effected either by fermentation during out-door storage, or by washing.

Until now, no industrial production of cement bound bagasse boards is known. However, in the near future the first mills will start operations in this field. Based on favourable experiments, Cuba intends to manufacture building material of the type bagasse-cement on a broad scale (59). In Mexico, a new factory for cement bound bagasse boards will be built by a German machinery manufacturing firm. A sample of the board, which will be manufactured ("VELOX-BAGASSE BOARD") had the specific gravity 0.65. That, in principle, the production of boards from agricultural residues is possible, has been proved by a firm which is engaged in this field (60). The results of the experiments in this company are summarised in Table 10. They are in accordance with those of a German manufacturer of machinery for such boards. This firm states that it is possible to produce cement bound boards from bagasse, cotton stalks, reeds, rice straw and rice hulls. In England, Chittenden and Flaws have made light-weight concrete bricks of good quality from rice hulls (58). A brick with the dimensions 230 x 113 x 58 mm had the specific weight of 0.97.

Table 10. Suitability of agricultural residues for cement bound building boards (results of a German machinery firm) (60)

Agricultural waste	Scale of experiments[1]	Suitability without pre-treatment	Suitability with pre-treatment
Cotton stalks	Laboratory Semitechnical Technical	not suitable	suitable
Peanut shells	Laboratory Semitechnical	not suitable	suitable
Flax waste	Laboratory	suitable	
Hemp waste	Laboratory	suitable	
Coconut fibres and meal	Laboratory	suitable	
Corn, stalks and leaves	Laboratory	suitable	
Rice hulls	Laboratory Semitechnical	partially suitable	suitable
Reeds	Laboratory	partially suitable	suitable
Wheat straw	Technical	not suitable	suitable, with reservations
Sugar cane bagasse	Technical	not suitable	suitable, with reservations

1/ Scale of experiments:
1) Laboratory means: experiments with small specimens only;
2) Semi-technical means: experiments with building elements;
3) Technical means: experiments on an industrial scale.

4. Properties and qualities of the products obtained from the various raw materials enumerated above

As already mentioned, no commercial cement bound boards or building blocks made from agricultural waste are at present on the market, but we know from laboratory, semi-technical and industrial scale tests that the boards from cement and agricultural residues have nearly the same properties as those made from wood-wool, e.g.

1. the boards can be produced in nearly all desired, practical sizes, with the specific gravity of wood;
2. the panels can be sawn, bored and nailed like wood;
3. they can be painted and plastered;

4. they are fire-proof;
5. they are resistant to fungi and termites;
6. they are sound- and vibration-proof;
7. the shrinkage is very low;
8. their thermal conductivity is low;
9. the boards are rain-proof.

Therefore, such products are well-suited building materials for exterior and interior walls, ceilings, floors and roofs. But, in tropical countries, insects may prefer the fine hollows of the porous board as nests. In such cases the board should be plastered.

According to the type of building material, the specific gravity may vary widely. Thus the "VELOX-Bagasse Board" referred to above has a specific gravity of 0.65 and the light-weight rice hull brick of the Tropical Products Institute 0.95. Miller and Fishman quote (55) that the specific gravity of their board can be varied between 0.64 and 1.6. Boards with higher density (like the "Century Board" of Elmendorf which has a specific gravity of 1.05 to 1.20) may preferably be used for exterior constructions.

The suitability of cement bound boards from agricultural residues also depends on the shape and length of the agricultural waste. Long particles give, in general, better quality than small, shell pieces. The values for the mechanical properties of boards manufactured from agricultural waste should correspond to the accepted standards, e.g. DIN 1101. However, under certain local circumstances deviations may be tolerated.

5. Modifications which have to be made to the standard wood-wool/cement board plants to process each agricultural waste

The process for the manufacture of cement bound boards is, beginning with the mixer, for wood-wool and agricultural residue nearly identical. A factory which intends to change from wood to agricultural waste as raw material, has, therefore, to modify the first steps of the process:

harvesting;
transport;
storing;
reduction of the waste to finer pieces;
depithing (of bagasse), if necessary, by screening or air separation.

With regard to harvesting, transport and storing, the experience of the pulp and chip-board industry may be useful. Transportation and storing are severe economic problems, but the storing is, in addition also sometimes a biological one, e.g. with bagasse (61).

Bagasse from the older, conventional sugar mills is coarse and mixed with irregular, large stem pieces. On the other hand, uniform fine bagasse is delivered from the modern mills, which operate according to a diffusion principle. This difference may be the reason why some factories get cement bound boards of good quality (with bagasse from modern mills) and others boards of bad quality (with bagasse from old mills).

While storing bagasse, the fermentation process should be directed in such a way that the sugar residue disappears, but that the plant material does not deteriorate. At present it is not possible to give firm recommendations for the production line between the storage pile and the mixer, because as yet not a single plant for cement bound boards from agricultural waste has been built. Perhaps, instead of wood-wool machines, the following equipment is necessary:

Pre-press for baling bagasse;

Storage facilities;

Bale opener;

Shredder for desintegration of large particles;

Depithing unit.

The price for these modifications is compensated by the costs for all the machinery not needed for wood-wool manufacture. The modifications for other agricultural residues may be analogous. It is still uncertain whether the storage pile should be preserved, e.g. with boric acid, nickel salts or fungicidal gas.

6. Problems of cement binders and their selection for each material

Wood-wool boards are manufactured with gypsum, magnesite or cement as the inorganic binder (4,8). From these, gypsum cannot be used for exterior boards. According to Kollmann, the bending strength of mineralised light-weight boards depends on the relative humidity of the air, and this dependence is different for different binders. Wood-wool boards with cement as the binder have the lowest sensitivity, those with gypsum the highest and the boards with magnesite as the binding agent have values between those of the two mentioned boards (Table 11).

Table 11. Bending strength of mineral bound wood-wool board and its dependence upon the relative humidity*/ (66)

Relative humidity %	Bending strength (kp/cm^2)		
	cement	magnesite	gypsum
40	26	20	21
70	24	20	19
95	23	15	12

*/ The figures have been derived from curves.

On the other hand, cement causes a certain brittleness of the boards.

The development of the wood-wool board industry during the last two decades demonstrates convincingly that portland cement is the most suitable binder. All facts favour cement: it is cheap, of high quality and available in all countries.

The cement should be of rapid setting quality to enable a short working time in the process and to avoid technical bottlenecks. Unfortunately the setting of the binder is often strongly influenced by plant extractives, e.g. sugars, tannins and hemicellulose and also by sugar residue in bagasse. To overcome such difficulties, cement is "mineralised" with calcium hydroxide, calcium chloride, magnesium chloride, sodium silicate or cement milk. Some of these additives give undersirable side effects. Thus, all chlorides favour rust formation on iron; sodium silicate, because of its alkaline reaction, deteriorates the wood and plant particles and it makes the boards brittle. Therefore other salts have been proposed, e.g. alum, ferro-sulfate, thio-sulfate etc.

For improving the hydrophobic nature of wood, soaps, bitumen, asphalt and emulsions of paraffin are added.

Of course, the optimum water : cement ratio, the additives and the conditions have to be determined for each agricultural waste. In some cases the natural cement setting inhibitors are so strong that the mineralisation is without effect. In such cases water extraction may be successful. For the analysis of the inhibiting effect in fibrous material the determination of the hydration heat may be useful (65, 67)..

7. Measures of quality control and process control needed at various stages of production

Cement bound boards are building materials which are standardised. Guarantees require control, so that the product is available at all times in the same quality. In the manufacture of cement bound board control is necessary for:

Raw materials:

agricultural waste:

water and sugar content,

temperature in the pile

after shredding: particle screen analysis, presence of cement inhibitors

cement: uniformity, setting

additives: uniformity

Process: uniformity of the mixture (agricultural residue, cement, minerlising agent)

uniformity of mat forming

Product: specific gravity

dimensions

weight of board

bending strength

compressibility

8. Training needs and qualifications of key technicians for efficient plant operations

The production of cement bound boards from agricultural waste is a simple process. Nevertheless it is infected with difficulties, caused by irregularities of the raw materials. Changing to another type of agricultural residue or even to wood often necessitates special pre-treatments and mineralising methods. In such situations, the factory manager has to decide very quickly, in order to avoid the break-down of the production. A key technician should have knowledge of cement technology, machinery, testing of boards and the use of boards and hollow blocks in house building. The best way to become familiar with such problems is to work for a certain time in a foreign factory operating in the same field. Here the technician will learn the know-how he needs. This recommendation is especially important for developing countries. It is well known that some factories for wood-wool board stopped their production because they had no skilled key technicians. This could be avoided if the selection of key technicians had first priority.

9. Trends in future development of this industry (automation, new processes, economics of scale, etc.)

The technical processes for the manufacture of cement bound light-weight boards are well developed. At least two systems, those of Canali and Van Elten are extensively automated. It seems that no surprising new developments in this field have to be expected. Concerning new products, the use for pre-fabricated houses is becoming more and more interesting. Large construction elements of 8 m length are manufactured for the walls of factories and halls. Some boards of standard size are constructed as three-layer boards with a central layer of porous polystyrol plastic.

The economic situation in some countries is different. In the Federal Republic of Germany, the leading producer of wood wool-boards, production is declining (Table 12). This development is caused by the fact that more and more other products are penetrating the market, (these are asbestos cement boards, chip board, mineral fibreboard (made from the mineral adabas,) synthetic boards from polyurethane (e.g. "Herathan" of Deutsche Heraklith A.G.), fibre glass boards and mats etc. Instead of cement bound wood shape blocks, similar blocks of porous cement (e.g. "Ytong") are being used on a large scale for house building. For comparison, the prices of different boards are summarised in Table 13.

Table 12. Production of wood-wool board in the Federal Republic of Germany

Year	Mill. m^2	Year	Mill. m^2
1951	21.73	1958	31.54
1952	21.50	1959	36.38
1953	23.57	1960	38.22
1954	25.91		
1955	28.47	1965	40.76
1956	31.00	1966	38.80
1957	30.71	1967	33.64

Source: German Association for Light-weight Boards.

Table 13. Prices of different boards which compete with the cement bound light-weight board (Federal Republic of Germany) (1970)

Type of board	DM/m^2	
Eternit, 4 mm thickness	3.64	
Chipboard, urea resin, 8 mm	4.15	
Chipboard, phenol resin, 8 mm	5.30	
Gypsum board, 9 ½ mm	3.25	
Board from polyurethane plastic, 25 mm, surface: impregnated paper	6.80	
Cement bound wood wool board, 25 mm	3.25	
Wood wool board, 25 mm, magnesit bound	3.95	
"Isowand"- Board: polyurethane foam, on both surfaces metal sheets, painted	43.55 36.15	in quantities from 100 to 150 m^2 in quantities of more than 8,000 m2

Cement wood-wool boards are manufactured in many countries. For some of them, the capacity of this industrial branch is given in Table 14, but this list is not complete because some of the important countries are not mentioned, e.g. Japan, Sweden, U.S.A., U.S.S.R. etc.

There is a certain tendency for consolidation in the light-weight board industries. Thus in Sweden after the last war, more than 60 factories produced cement bound board. Since then 60 factories have closed and at present only 9 mills are still in operation. Japan had 64 plants in 1969 and will have an output of 505,000 m^3 in 1970. Besides this, there are 3 plants producing 50,000 m^3 (in 1970) of Durisol type products (69). It seems that USSR has a rather high production level of cement bound wood-wool boards, e.g. Arborit and Fibrolit but no figures are available. The total world production could be of the order of 2 million to 2.5 million m^3.

Cement bound light-weight boards could probably be interesting for some developing countries. But even if the board is cheap, there may be no market, because the population is strongly conservative in some areas and prefers the building traditions of their ancestors.

The possibilities of the new building boards have been tested in Indonesia (70). Boards with sufficient mechanical strength could be manufactured from Pinus and Agathis species, but not from bamboo. A comparative calculation demonstrated that the cement bound board could not compete with other materials (Table 15).

Table 14. Capacities of production of wood wool boards in some countries (68) in 1000 m^3 (F = number of factories)

Country	F	1965 Boards	F	1966 Boards	F	1967 Boards	
Australia	3	3.5	3	3.5	2	3.5	
Belgium	9	28	8	33	8	36	
Chile	1	2.5	1	2.5	1	2.5	
Czechoslovakia	7	127.5	7	127.5	7	127.5	
France	6	116.3	6	106.4	6	112.5	1968: F 6,200
Fed. Rep. of Germany	59	1019.0	59	970	55	841	
Guatemala	1	5	1	4.5	1	4	
Japan	62	270	65	310	64	370	1970: F 64,505
Malaysia	1	3.1	1	1	1	2	
New Zealand					1	1.6	
Panama	1		1		1		
Poland		110		100		115	
Switzerland	7		7		7		
Taiwan					1	38.8	
Thailand	1	1.5	1	1.8	1	1.8	
Yugoslavia	5	53	5	20	5	16.5	
Not specified:	Australia, Brasil, China, Cuba, Denmark, Finland, Greece, India, Italy, Netherlands, Norway, Spain, Sweden, USA, USSR. These countries have capacities for cement bound wood-wool board. Finland 1964: 157.000 m3.						

Table 15. Prices of house building materials in Indonesia, 1968 (70).
Rupies/m² wall (1 $ = 280 Rupies)

Materials	Rupies/m²
Bamboo mat	20
Teak or other broadleaved wood	200 - 400
Coniferous wood	120 - 180
Coniferous wood, preserved	160 - 230
Eternit (local production)	80
Eternit (imported)	350
Bricks	160
Limestone	168
Plaster	60
cement bound wood wool boards, plastered, without fitting	300
cement bound wood wool boards, plastered on both sides and nailed on wood frame	400

In other tropical countries the situation may be more favourable. Tests should be made in all cane sugar producing countries where no industry exists as yet, but where abundant amounts of bagasse would be available delivered ex-mill. Bagasse has the advantage over other agricultural wastes in that its harvesting cost is usually borne by the sugar industry and transport costs could be minimised if the plant is located near a sugar mill. The boards may be used in constructing schools, police stations, administrative buildings etc. The new material is especially useful, when large numbers of houses are suddenly needed, e.g. after disastrous earthquakes (Morocco, Peru, Turkey, etc.) or for reconstruction after wars.

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