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PARTICLE BOARD FROM ANNUAL PLANT WASTES [1]

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The flow sheets for particle board plants based on bagasse and jute, contained in figures 3 and 6 respectively, are reproduced here by permission of Bureau d'Etudes et Laboratoire de Chimie Industrielle S.A. Verkor, Lauwe, Belgium, and may not be further reproduced without their authorisation.

PARTICLE BOARD FROM ANNUAL PLANT WASTES

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INTRODUCTION

We, first of all, would like to call your attention to the fact that no distinction be made between particle board produced from annual plant wastes and particle board produced from wood. As far as board utilization is concerned, the only distinctive facts are the quality and properties of the manufactured product, depending more on the type of board than on the raw material from which the board is made.

It may well be noted that for most of the annual plant wastes a specific method is required to prepare the particles suitable for board production, and that if this particle preparation is not adapted to the raw material, rather inferior end products may result.

The industrial production of particle board from annual plant waste was first introduced in 1948, when flax shives were used to produce the Linex flaxboard, according to the Verkor process.

The description of this flaxboard manufacturing process has been given with sufficient detail in the literature (1), so it is not necessary to repeat it here. The production of flaxboard may be considered a very typical example of the use of an initially worthless agricultural waste for the production of a very valuable end product which is used extensively in the building and furniture manufacturing industries.

Taking an example from the production and application of flaxboard, several other annual plant wastes were examined with the purpose of producing similar boards. A few experiences are discussed hereafter.

Besides lignocellulosic raw material, the production of particle boards requires a binding resin which only makes up to 8 to 12 % of the weight of the board, but represents a cost often equal to or higher than the cost of the lignocellulosic material, especially in developing countries, where resins have to be imported.

Additional investigations should be made as to whether products available from local sources are usable as binding agents. In this connexion satisfactory results have been obtained by several research workers with certain types of tannin extracts. Some experiences are discussed hereafter.

The experience in Europe extending over a number of years has proved that particle board in general, but especially flaxboard, is particularly useful in the building industry. Through the use of prefabricated elements, it allows shorter building times and reasonable costs.

For some applications in the building industry, the boards should be treated for protection against fungal attack and mould growth and the manufacturing of particle boards with phenolic resins gives a supplementary guarantee for longer life, especially under conditions of high relative humidity or for applications where direct contact with water may occasionally occur.

The manufacturing of the phenolic flaxboard is treated hereafter.

1. PHENOLIC RESIN BONDED FLAXBOARD

The first trials to produce phenolic resin bonded flaxboard did give rather negative results, and board satisfying the standards set up in the Federal Republic of Germany could not be obtained consistently.

Two main problems, each resulting from the specific properties of both raw materials, had to be faced to produce a satisfactory phenolic flaxboard:

(a) the curing of the phenolic resins normally requires a high temperature and pressure. Both these conditions are difficult to realise when producing low density flaxboard for the building industry. Its own insulating properties reduce the heat transfer from the press to the core of the board so that the curing has to take place at lower temperatures. The lower board density implies that actually lower pressure is applied on the glue lines, rendering a perfect gluing of the particles more problematic.

(b) The surface of the original flax shives is not in an optimum condition to be glued. The inner surface of the shives has a layer of soft, low-resistance pith cells easy to be glued but not able to transfer high bond strength from one shive to the other, especially not under wet conditions.

As a result of microscopic studies and careful technological investigations on the flax shives, of which all details have been published by ourselves (2), it has been found that a high quality phenolic resin bonded flax board can be produced even at low densitites. At comparable density such boards are superior to wood based particle boards.

To obtain this result it is necessary to observe the following points:

The flax shives must be particularly well "cleaned", this means that all impurities which may be present in the shives, such as: dirt, roots, fibres, seeds, seedhurls, cereal straw and other grasses, must be eliminated.

It is necessary to prepare the shives mechanically in such a way that the parenchymatous cells (pith) are as thoroughly as possible removed; The conditions at pressing must be adapted to the particular material and the type of resin.
It is advantageous to manufacture a 3-layer board so as to have more flexibility in setting up the technological details such as resin content, moisture content, hardener system, etc.

Considering all these points, boards with the properties given in Table I have been produced:

TABLE I

		1.	2.	3.
Density kg/m3	$\bar{X}$	528	515	528
	R	21	21	25
Modulus of rupture kg/cm2	$\bar{X}$	189	179	197
	R	24	6	33
Modulus of elasticity kg/cm2	$\bar{X}$	31120	29220	31500
	R	2200	2700	3000
Internal bond kg/cm2	$\bar{X}$	5.94	5.77	5.78
	R	1.15	1.52	1.64
Internal bond after 2 h. boiling tests kg/cm2	$\bar{X}$	1,44	1.44	1.52
Swelling after 2 h. immersion in water 20°C - %	$\bar{X}$	6.00	6,31	6.37
	R	2.00	0,72	0.41
Swelling after 24 h. immersion in water 20° C - %	$\bar{X}$	10.54	10,06	10.74
	R	0,54	0,57	0.41
Swelling after 2 h. boiling	$\bar{X}$	13.97	13.93	14.56

		4.	5.	6.
Density kg/m3	$\overline{X}$	508	520	510
	R	38	38	34
	s^2	284	160	112
Modulus of rupture kg/cm2	$\overline{X}$	159	166	163
	R	15	38	37
	s^2	43	147	160
Modulus of elasticity kg/cm2	$\overline{X}$	24475	30055	29577
	R	2300	5200	3700
Internal bond kg/cm2	$\overline{X}$	5.92	6.10	6.20
	R	1,10	1.20	1,10
	s^2	0.478	0,114	0,095
Internal bond after 2 h. boiling test kg/cm2	$\overline{X}$	1.90	1,90	2,01
	R	0.40	0,14	0,58
	s^2	0.0187	0,029	0,048
Swelling after 2 h. immersion in water 20° C - %	$\overline{X}$	7.18	5,06	5.50
	R	1.05	1,90	1,63
	s^2	0.118	0,397	0.291
Swelling after 24 h. immersion in water 20° C - %	$\overline{X}$	8.35	8,84	9.17
	R	1.09	0,57	0.60
	s^2	0.138	0.0397	0.045
Swelling after 2 h. boiling - %	$\overline{X}$	10.82	11,20	10,76
	R	0.51	0,57	0,59
	s^2	0.056	0,023	0,092

$\overline{X}$: average of 10 measurements;
R : range between maximum and minimum value;
s^2 : variation.

Test series 4, 5 and 6 were made with an additional quantity of sodium hydroxide, which under some conditions improves the quality of the phenolic boards.

Complementary to the laboratory test programme these boards were also tested for their resistance against exterior conditions.

Mr. Carré of the "Laboratoire de l'Etat" of Gembloux, Belgium (3), has subjected this board together with a whole series of competitive phenolic resin bonded wood particle boards to the usual accelerated testing methods as well as to an external exposure test, and although the tests are not concluded yet, some preliminary observations after one year of exposure are available and are given in tables II, III and IV.

The following tests and "accelerated aging" tests were carried out:

V 20 1/ : immersion in water at 20° C for 2 h;
V 70 1/ : immersion in water at 70° C for 5 h;
V 100 1/ : immersion in water at 100°C for 2 h;
I L T 2/ : long term immersion: 43 days at 13° C;
V P S 2/ : immersion for 42 days at 13° C after applying a vacuum of -0.8 kg/cm2 for 2 h. and a pressure of 6 kg/cm2 for 22 h. while the sample is immersed.

3 V 313 3/ : 3 cycles of the V 313 accelerated aging testing cycle consisting of:
72 hours immersion in water at 20° C;
1 day exposure to -12° C free standing in air;
3 days drying at 70° C in air.

A.T. 2/ : Exposure to an atmosphere of 20° C and 95 % relative humidity for 85 days.

I.: External exposure on wire netting at an inclination of 30°, face to the West.

I_1: after 5 weeks exposure;
I_2: after 6 months exposure;
I_3: after 1 year exposure.

After these tests the samples were reconditioned at 2o° C and 65 % relative humidity and tested for their permanent swelling, remaining flexural strength, and remaining internal bond.

Results are given for a few typical boards of good average quality specified as follows:

UFB: wood particle board with urea formaldehyde resin;
UFL: flax board with urea formaldehyde resin;
MB: wood particle board with melamine formaldehyde resin,
PB: wood particle board with phenolic resin;
PL: flax board with phenolic resin (reference board of the foregoing laboratory tests).

1/ Corresponding to standards set up in the Federal Republic of Germany.
2/ No official testing procedure followed.
3/ French accelerated aging test.

TABLE II

Permanent swelling in percentage of initial thickness

Type	density	V20	V70	V100	ILT	VPS	3V313	AT	I_1	I_2	I_3
UFB	590	6.5			8.3	6.8	19.8	2.8	11.2	16.3	D
UFB	630	4.9			8.2	7.6	17.7	2.0	5.2	10.6	D
UFL	540	6.3			8.5	7.8	23.6	2.5	10.1	17.1	D
MB	660	1.2	15.9		3.2	2.9	11.8	0.2	1.8	4.3	9.5
MB	670	1.7	9.4	19.7	4.9	4.5	8.1	1.7	2.7	4.8	9.5
PB	730	2.9	5.2	7.0	2.9	3.5	5.1	1.2	3.3	3.5	5.6
PB	690	3.8	6.7	7.8	4.7	5.4	7.7	1.6	3.2	3.9	5.5
PL	540	3.0	4.1	5.3	3.3	3.0	5.7	1.4	3.0	2.8	4.6

TABLE III

Remaining flexural strength in % of the initial strength of rupture

Type	V20	V70	V100	3V313	A.T.	I_1	I_2
UFB	93			68	95	64	43
UFB	87	40		63	106	86	73
MB	96	47		69	103	93	
MB	84	80	49	90	110	94	
PB	88	81	82	89	101	90	
PB	88	86	89	79	101	97	
PL	89	88	72	70	101	94	

TABLE IV

Remaining internal bond in % of the initial strength of rupture

Type	V20	V70	V100	ILT	VFC	3V313	AT	I_1	I_2
UFB	57	0	0	51	45	26	73	17	15
UFB	62	0	0	50	55	32	76	52	30
UFL	68	0	0	58	56	30	9	32	13
MB	80	35	0	87	85	33	106	88	
MB	96	47	18	73	75	27	92	76	
PB	85	87	77	75	86	47	99	75	
PB	66	55	58	61	41	30	87	69	
PL	80	84	75	62	90	27	104	71	

Tables II, III and IV are published with the courtesy of Mr. Carré.

The laboratory tests, as well as the "accelerated aging" tests and the results obtained after external exposure, prove that excellent phenolic resin bonded boards can be produced from flax shives and that their properties are at least equal if not superior to the properties of phenolic wood particle boards. It is to be expected that with similar car in the particle preparation, other waste materials from annual plants will give equally satisfactory results.

2. BAGASSE PARTICLE BOARD

2.1. Board production

Bagasse, the residue of sugar cane after sugar extraction, has already been found, but only to a limited extent, to be valuable in paper manufacturing and in fibre board and hardboard production, before the particle board industry showed any interest in this raw material.

Initially, not all attempts to utilise bagasse for particle board production were successful. In some cases the failure was due to a misconception of the board manufacturing plant itself, in some other cases it was a lack of market availability, in yet other cases it was an incorrect technological processing of the raw material resulting in a second quality board which could not successfully compete with other boards and materials already existing on the market.

Meanwhile, learning from the failures but especially through more extensive research and hence better knowledge of the properties and physical structure of the material, better processes for both raw material conservation and particle preparation were established.

One of the main problems encountered when using bagasse as a raw material for board production is the storage of the bagasse for the period between the grinding seasons.

In most of the sugar cane growing areas the grinding season does not extend over more than five to six months.

The solution generally adapted for the storage of the bagasse in the pulp and paper industry involves baling it directly at the sugar mill. However, the problems attached to this are manifold. The baling operation is costly, it requires proper procedures for piling and it will still cause a fibre loss of 10 % or more owing to deterioration.

In the particular case of particle board production an additional problem is that uncontrolled fermentation of the baled bagasse may not only decrease the yield of fibre but the remaining material can be degraded to a point that only boards of second quality can be manufactured from it. As a matter of fact it has been found that contrary to the generally accepted principles in the pulp and paper, fibre board and hardboard industries, where it is considered that for quality products the bagasse must be depithed as far as possible, this is not the case for particle board manufacturing (4). On the contrary, it is preferable to maintain as far as possible the natural structure of the plant, especially of the particles obtained from the exterior part of the stem. Only the soft central pith should be completely removed. The difference in density and hence in physico-mechanical resistance between a particle from the outer part of the stem and from the centre of the stem is clearly shown by the photomicrographs in figures 1 and 2.

It is obvious that the reduction of this outer part to the size of the original fibre creates the need to rebuild a similar structure afterwards in the board, requiring unnecessarily high quantities of resin.

It has also been found by ourselves that an excessive beating of the bagasse during the mechanical depithing may considerably reduce the original stiffness of the fibres and hence also the modulus of elasticity of the board manufactured with these fibres.

Informatively, a simplified material flow diagram in a bagasse particle board plant according the Verkor principle is given in figure 3 and described hereafter.

The green bagasse coming from the sugar mill by a scraper or by conveyor (1) is fed over a magnet (2) to eliminate scrap metal and a feed regulation device (3) to the depithing mills (4). By a pneumatic transporter (5) the bagasse is then conveyed to special screens (6) to separate the loose pith. The pith is generally sent back to the sugar mill to be used as fuel. From the screens the bagasse is transported by a conveyor belt (7) to the refining mills (8).

The refining is regulated according to the initial fineness of the bagasse and the subsequent requirements of board quality (homogeneous or 3-layer build-up, more or less fine surface). A pneumatic transporter(9) brings the bagasse from the refiners into a dryer (10) where the moisture content is brought down from 50 % to 5 %. The pneumatic circuit of the dryer (11) brings the material to a screen (12) to separate a supplementary quantity of pith liberated during the refining, (in the case of a 3-layer board the ground [fibres are separated] bagasse into 2 qualities, the finer quality is used for the surface layer while the coarser quality is used for the core layer).

From the screen the material is conveyed (13) into a measuring bin (14) and fed in a glue blender (15) provided with a complete glue mixing unit (16) followed by a pneumatic transporter (17) and a mat-forming station (18). The mat is formed in a frame (19), pre-pressed in a cold pre-press (20), weighed (21) and conveyed into a multi-daylight hot press (23) provided with a loading (22) and an unloading (24) lift.

After pressing, the board is trimmed by a special trimming saw (25) cooled in a cooling tunnel (26) and sanded on both sides with a drum or wide belt sander (27) and stacked (28).

The dust from the second screening, from the sanders and from the trimming saw is collected by a single pneumatic conveyor (29) stored in a special dust silo (30) and used as fuel for the main boiler or eventually the dryer.

It immediately appears that the differences between a wood and a bagasse particle board plant are to be found in the particle preparation section, the depithing being the essentially different stage.

2.2. Board production cost price

To calculate the cost price of the bagasse itself, two distinctly different situations have to be considered:

(a) whether excess bagasse is available,
(b) whether all bagasse is used as fuel for the sugar mill.

If excess bagasse is available, one may consider that at the sugar mill it has no value, and perhaps even supplementary costs are necessary to burn it in an incinerator. But although the bagasse has no value at the sugar mill, it will have a certain value once it is ready to enter the board plant.

During the grinding season and in the case of a board plant integrated to the sugar mill, the green bagasse does not represent a calculable cost. Between the grinding seasons however, thebagasse has to be stored and requires handling costs and investments. Figures based on different local conditions were published earlier (5) (FAO-1955) and should be adapted to actual salaries and the cost of machinery and materials. It is estimated that the cost of baled bagasse delivered at a board plant (with a capacity of 120 tons of bagasse per day, a labour cost of US$ 1 per hour, and a grinding season of 6 months) will vary between US$ 2 and US$ 4 per ton of baled bagasse. In percentages this cost is built up approximately as follows:

cost of wire: 8.8 %
capital cost of baling station: 1.2 %
capital cost of storage area: 0.9 %
capital cost of equipment: 15.8 %
labour: 73.3 %.

In the case that excess bagasse is not available and that its replacement by fuel oil, natural gas or some other fuel is necessary, the cost of the bagasse increases quickly and in direct proportion with the cost of the locally available fuel.

The corresponding heating value of green bagasse to fuel oil is 1 to 6. From this figure it is easy to calculate the value to be used for the bagasse. At a cost of US$ 20 per ton for the fuel oil, the green bagasse has a value of US$ 3.33 per ton.

Besides the replacement of fuel it will also be necessary to convert the boilers. This may cost from US$ o.1 to o.3 per ton of dry bagasse.

Assuming no excess bagasse is available, average conditions for labour and fuel costs, a capacity of 120 t baled bagasse per day and a grinding season of 6 months per year, the average value of the bagasse delivered to an integrated board plant with a production capacity of 45 tons of board per day will be:

Six months fresh bagasse at:

fuel replacement value: US$ 3.33 per ton
boiler conversion cost: US$ o.15 per ton
US$ 3.48 per ton.

Six months stored bagasse at:

fuel replacement value: US$ 3.33 per ton
boiler conversion cost: US$ 0.15 per ton
handling and storing cost: US$ 3.00 per ton
US$ 6,48 per ton

Average value over the whole year: US$ 4,98.

Based on this value for bagasse, an example of a particle board production cost price calculation is given hereafter.

The calculation is based on the following technical specifications.

Raw material:	6 months fresh bagasse; 6 months stored bagasse.
production capacity:	45 tons of board per day, at 300 working days of 3 shifts: 12,500 t/year.
board specification:	density 600 kg/m3, thickness 16 mm.
glue consumption:	85 kg of dry urea formaldehyde resin per ton of board.
power consumption:	260 kW/ton of board.
heat consumption:	1,300,000 kcal/ton of board.
direct labour:	22 men/shift.
indirect labour:	6 men/day.

<u>(a) Raw material:</u>	<u>Annual cost:</u>
Bagasse:	
(output 1 ton of finished) board per 2.5 tons of fresh bagasse	
12,500 t x 2.5 kg x 4.98 US$/ton	US$ 155.625
Synthetic resin.	
urea formaldehyde resin at o.2 US$/kg	
12,500 t x 85 kg x 0.2 US$/kg	US$ 212.500
Supplementary chemical ingredients:	
hardener: 1 % on resin at o.2 US$/kg	
12,500 t x 0.85 kg x 0.2 US$/kg	US$ 2.125
Paraffin:	
5 % on resin at o.2 US$/kg	
12,500 t x 4.25 kg x o.2 US$/kg	US$ 10.625

<u>(b) Power consumption:</u>	
260 kW/ton at 0.02 US$/kW	
12,500 t x 260 kW x 0.02 US$/kW	US$ 65.000

(c) Heat consumption. **Annual cost:**

The heat requirement for the board production and drying of the bagasse is supplied up to about 50 % by the available wastes from the sanders, the trimming saws and the dust screens. The remainder has to be supplied by fuel oil at US$/kg 0.02 with a heating value of approx. 10,000 kcal/kg.

$$12{,}500\ \text{t} \times \frac{650{,}000\ \text{kcal}}{10{,}000\ \text{kcal/kg}} \times 0.02\ \text{US\$/kg}$$ US$ 16,250

(d) Direct labour:

Considering an average labour cost of 1 US$/hr

300 d. x 24 hrs x 22 men x 1 US$/hr US$ 158,400

(e) Indirect labour:

Consisting of:		
1	director	800 US$/month
1	technologist	500 US$/month
1	maint.engineer	500 US$/month
1	accountant	300 US$/month
1	secretary	200 US$/month
1	forward.clerk	200 US$/month
		2,500 US$/month

total per year: 2,500 US$ x 12 months US$ 30,000

(f) Depreciation:

Buildings consisting of:

main manufacturing hall
board storage facilities
offices
boiler room
auxiliary services

estimated total cost: US$ 80,000

yearly depreciation: $\frac{\text{US\$ } 80{,}000}{20\ \text{years}}$ US$ 4,000

		Annual cost.
Machinery:		
European machinery FOB:	US$ 1,000,000	
overseas transport local transport loading and unloading	US$ 40,000	
local supplies.	US$ 40,000	
erection costs:	US$ 80,000	
total machinery:	US$ 1,160,000	
yearly depreciation:	US$ 1,160,000 10 years	US$ 116,000
Land site:		
requirements, about 3 ha.		
no depreciation.		
(g) Overhead and Miscellaneous:		
Estimate:		US$ 20,000
(h) General maintenance and supplies:		
Oils, greases, abrasive papers, knives, saws, etc.		
Estimated at 1.4 US$/ton		
12,500 t x 1.4 US$/ton		US$ 17,500
(i) Capital cost:		
Land site:	US$ 4,000	
buildings:	US$ 80,000	
machinery:	US$ 1,160,000	
working capital:	US$ 200,000	
	US$ 1,444,000	
at 9 % interest:		US$ 129,960
	total per year:	US$ 937,895

Cost price of board:

per ton.	$\frac{\text{US\$ } 937,895}{\text{tons } 12,500}$	=	75.04 US$/ton
per cubic metre.	75.04 x 016	=	45.024US$/m3
per square metre.	45.024 x 0.016	=	0.72 US$/m2
per 1,000 sq.ft	$\frac{0.72 \times 1000}{10.764}$	=	66.89 US$/1000sq.f.

Note:

On this cost price savings are possible on the following points:

Bagasse value:

It is only common sense that a more rational heating programme in the sugar mill, with maximum calorific recuperation, better insulation, etc., could considerably increase the quantity of excess bagasse available for other purposes at a nominal price.

Several of the larger sugar mills could easily supply a medium capacity board plant with their excess bagasse alone.

Bagasse storage:

A lot of unsolved problems still exist in bagasse storage. Baling, which was quite generally adapted by pulp and paper mills, is now more and more abandoned in favour of more economic systems such as bulk storage and briquetting.

The bulk storage of green bagasse is not suitable for particle board production if special precautions to protect the material from fermentation and rotting are not taken.

Neither is the briquette system yet suitable for particle board production, as the bagasse fibre is partially damaged by the high pressure during briquetting.

These problems are now being studied from several angles and satisfactory solutions will certainly be available in the near future.'

Synthetic resins:

The price of synthetic resins is rather high in most of the developing countries, as there is no local production, transport from overseas is expensive and sometimes high import duties are applied. However, exemption of the customs duties can often be obtained during the first years of production.

In some countries, local production of resin from formaldehyde and urea may be worthwhile, especially if one of these main ingredients is already produced locally, or if duties are very high on condensed resins but not on basic chemicals.

In some other countries natural products may eventually replace, at least in part, the resins otherwise to be imported. In this field quite satisfactory results have already been obtained with tannin extracts.

Heat consumption:

The need for supplementary fuel in the board plant may be reduced to practically nil if the bagasse is dried with the flue gases from the sugar mill.

Labour:

Labour savings may be obtained through perfect organisation, but especially through increase of the production capacity of a plant. Most of the working stations in the board plant will require the same control and work even for double or triple production.

This applies especially to the indirect labour. Also, the most labour is involved in handling the raw material (bales) so that if better storage systems can be worked out, considerable labour savings are possible.

Summarising, one may consider this cost price as very interesting, even though the plant taken as an example was rather small. However, for most developing countries where the market for board exists potentially but still has to be developed, one should also not over-estimate the immediate absorption capacity of the market.

Wherever possible, medium capacity plants between 30 and 90 tons of board per day should be considered.

Although a particle board plant can be easily started up and shut down it is not economically justified to run such a plant with only 1 or 2 shifts per day, as the total investment cost is too high and working at only 40 or even 65 % of the production capacity would burden the cost price heavily.

2.3. Phenolic resin bonded bagasse board

For the developing countries where the demand for furniture is low it may appear at first glance that a market for particle board does not exist. However, in all these countries there is a great demand for housing and it is certainly in this field that a considerable quantity of board can be used.

Very often the board used in the building industry must satisfy special requirements, for example better moisture resistance and especially better aging properties under moist conditions at high temperatures. A type of board fulfilling these requirements is the phenolic resin bonded board. A few months ago an industrial test run was done on the Linex-Panofor production line in Mariembourg, Belgium, according to the Verkor process. The results of the test run are given for information in table V.

The technical specifications of the board were as follows:

nominal density:	700 kg/m3	
thickness:	19 mm	
3 layer board		
glue content:	surface:	11 % dry resin on dry bagasse;
	core:	10 % dry resin on dry bagasse;
size of the board:	1,220 x 3,400 mm	
pressing cycle:	15 minutes	
pressing temperature:	165° C.	

TABLE V

Physical properties

		1.	2.
Density kg/m3	$\bar{X}$	692	713
	max.	714	721
	min.	671	704
Modulus of rupture kg/cm2	$\bar{X}$	266	262
	max.	289	286
	min.	249	246
Modulus of elasticity kg/cm2	$\bar{X}$	27,950	28,010
	max.	30,200	29,300
	min.	26,100	27,300
Internal bond kg/cm2	$\bar{X}$	7.40	6.91
	max.	8.96	7.46
	min.	5.80	5.68
Swelling in % after 2 hrs immersion at 20° C.	$\bar{X}$	3.26	4.00
	max.	3.69	4.57
	min.	2.87	3.58
Swelling in % after 24 hrs immersion at 20° C.	$\bar{X}$	12.84	13.56
	max.	15.81	14.94
	min.	11.91	12.88
Internal bond after 2hrs boiling water - kg/cm2	$\bar{X}$	2.31	2.20
	max.	2.69	[illegible]
	min.	1.94	1.86
Screwholding - kg	surface	132.5	
		134	
		129	
	edge	111.5	
		117.3	
		106.5	

These results prove that also with bagasse excellent phenolic resin bonded particle boards can be manufactured. In the above mentioned test run no low density boards were produced but as insulation is of minor importance for most of the applications in bagasse-growing countries this type may be of less importance, except for roofing purposes, where an insulation against the heat of the sun on the roof may be well appreciated, or in places where air-conditioning is applied.

There are, however, good reasons to believe that what has been done with flax shives can also be done with bagasse and with other plant wastes.

3. OTHER PLANT WASTES

The two foregoing raw materials, flax shives and bagasse, represent two quite different types of annual plants from the botanical point of view. Flax is a typical representative of the dicotyledones while sugar cane is a monocotyledone. They represent extreme structure differences (see photomicrographs 1-2 and 4-5). The structures of numerous other plants can be placed in between the two foregoing, and the experience gathered with the above materials allows us to say with a certain a priori that with appropriate treatment useful results will be obtained. This has already been the case with hemp in Europe and with cotton stalks and jute sticks in Asia where these materials are used according to Verkor processes (6). Other materials have already been the subject of more or less extensive laboratory studies, some preliminary considerations are given below.

3.1. Hemp, jute and other bast fibre plants

The material flow diagram in a particle board plant based on hemp or jute is similar to that of a flaxboard plant. The principle difference is due to the fact that the stems of hemp and jute are considerably thicker than the flax stem and that therefore supplementary cutting is necessary.

Whereas hemp is delivered to the board plant already in shives, jute is not broken at all as the fibres are still peeled off by hand and the sticks are delivered to the board plant in their full length. A double cutting operation is therefore required. Fig. 6 gives the material flow diagram of a jute particle board plant according to the Verkor process.

The sticks are cut in the knife mills (1), conveyed by a pneumatic conveyor (2) to a special screen (3) to eliminate the remaining fibres. A bucket elevator (4) brings the material into a measuring bin (5) over a screen (6) to the cutting and refining mills (7) where the bigger chips are reduced to suitable particles.

The material is then transported by a pneumatic conveyor (8) to a de-dusting screen (9) and by a bucket elevator (10) over a distributing screw conveyor (11)to a storage silo (12). From the silo the material is conveyed by a screw conveyor (13) to a measuring bin (14) from which the glue blender is systematically supplied (15). The glued particles are brought to correct moisture content in a conditioning chamber (17) and pneumatically conveyed (18) to the mat forming station (19).

The mat is formed in a frame (20) pre-pressed in a cold pre-press (21), weighed (22) and conveyed into the automatic loader (23). When the loader is filled, all mats are simultaneously brought into the hot press (24) while the pressed boards are pushed into the unloading lift (25).

The pressed boards are then trimmed (27), cooled in a cooling tunnel (28), sanded on both sides with drum or wide belt sanders (29) and stacked (30).

The dust from the whole plant is collected by a pneumatic conveyor (31) in a dust silo (32) to be used as fuel for the boiler.

It may be considered that with some minor adaptations the same process can be used for some other bast fibre plant wastes such as for example kenaf, theel and ramie.

3.2. Cotton stalks

Cotton stalks were thoroughly examined before it was decided to use them for particle board production. It was immediately noted that under a single nomenclature very different materials had to be considered.

In some countries the stalks had a maximum height of 40-50 cm with a diameter of not more than 4 to 8 mm while in some other countries the height reached 100 to 150 cm for a diameter of 10 to 20 mm. It is obvious that the latter material is far more interesting for board production, and that with the first material a very careful study should be made as to whether a project is still economically feasible or not, as the yield of usable raw material decreases quickly in proportion to diameter of the stem.

The preparation of particles from cotton stalks requires a few specialized operations such as boll (grain capsule) elimination and washing of the pre-cut stalks.

The gluing, forming, pressing and finishing are done according to the usual technology for annual plant wastes.

The main problem in the use of cotton stalks, however, is much more in the collecting and storage of the stalks than in the actual board production. The raw material is available only during a relatively short period (six weeks) and must be collected, transported and stored during this period. It is generally known that the storage of large volumes of lignocellulosic materials subject to degradations by fungal attack, weather exposure and insects is no small problem. It is therefore worthwhile to consider the eventual combination of cotton stalks with wood waste, the cotton stalks being used after the cotton growing season for at least five to six months, while for the rest of the year the plant would operate using wood only.

This double possibility requires a few more machines, but it may render a project much more attractive.

3.3. Rice hulls and peanut shells

Considerable amounts of these wastes are available already in concentrated areas and in several cases even in one single mill. While they are wastes of an industrial process, they are also regularly available over extended periods, they should thus be particularly interesting materials to work with. However, the limited experience available with these raw materials is not very encouraging and rather important difficulties were encountered with their gluing. The photomicrographs as well as the macrophotograph in fig. 7, fig. 8 and fig. 9 show us partially why this is so.

The surface of both the rice hulls and the peanut shells is very irregularly shaped and corrugated. Close contact of one particle, to another to be bridged by a glue line, is therefore very difficult.

Furthermore as both materials form the natural protection of the seed, they are therefore themselves naturally protected and it is very difficult to moisten them with any foreign material. New techniques which could loosen up the basic material more, and eliminate this resistance to the glue will therefore have to be developed.

3.4. Cereal straw

Although cereal straw is used to produce a special type of board it it not used in conventional particle board production. Again, the original structure of the plant is such that gluing is practically impossible by the conventional binding systems.

Therefore, either the structure of the material has to be altered in such a way that sufficient gluable surface becomes free to allow each particle to be glued to another, or new resins with a specific adherence for the outer straw surface must be developed, or existing resins having this adherence must be made available at lower prices.

3.5. Maize

The structure of maize as shown in the photomicrographs fig. 10 and 11 is basically similar to the structure of bagasse, and although the fibres are finer there is no doubt that this material can be used to manufacture a satisfactory particle board.

The problem of collecting and storing the stems should be examined and a detailed feasibility study made to assure the economic viability of an eventual project based on this raw material.

3.6. Sisal, abaca and coconut fibre

All these fibres have already been the object of laboratory tests and there are no fundamental difficulties in producing boards from them. However, as the production of these fibres involves considerable manual labour they are rather expensive and unless very special local conditions exist, their use as a raw material for particle board is difficult to consider for producing a competitive end product.

The specifications of board qualities obtained with these raw materials have been published earlier (7) and are quite satisfactory.

3.7. Bamboo and reeds

No particular difficulties are to be expected from the use of bamboo. Its processing will be very similar to that of normal wood particles and only minor technological adaptations will be necessary. Board properties of bamboo have already been published (7). They are quite satisfactory and will allow the board to be used for all types of applications. Reeds, although similar in structure to bamboo, will certainly give more problems.

The centre of the reed stem contains more pith cells than does the bamboo, and the quantity of suitable fibrous material in proportion to the outer stem surface is much lower. As the outer surface cannot be directly glued it has to be broken down mechanically to liberate sufficient gluable surfaces. It is certain however that more research will yield satisfactory processes.

3.8. Palm leaves and palm trunks

Although the palm trunk is not an annual plant, it is a representative of the monocotyledones and its structure is much more comparable to the structure of certain annual plants (e.g. sugar cane) than to that of the conventional trunks.

Very little research has been done on the use of the palm trunk itself, and still less on the use of its leaves or fruit stems. All of these materials however are usable and satisfactory boards could be produced if some further research work is done to establish optimum processes.

More information on availability and possible methods of collecting and transporting should be gathered to establish detailed feasibility studies.

Results obtained with palm leaves and fruit stems have been published earlier (7).

Complementary results obtained with coconut palm trunks are given hereafter:

density, in kg/m3:	648
thickness, in mm:	10
modulus of rupture, in kg/cm2:	260
modulus of elasticity, in kg/cm2:	22,900
internal bond, in kg/cm2:	8.75
screw holding, in kg - face:	130
edge:	90
swelling in % after 2 hrs immersion at 20° C:	4.8
24 hrs immersion at 20° C:	11.4

These results are excellent, but it should be borne in mind that under the same terminology palm trunks', many different materials are considered, and density and moisture content may vary considerably between species. Detailed investigations should precede each industrial project.

4. TANNIN EXTRACTS AS A PARTICLE BOARD BINDER

Due to their extensive use in the leather industry, the chemical structure of most of the important tannin extracts has been the subject of extensive investigations by several scientists, and although their exact structure is difficult to determine, it is known that the basic constituents of all tannins are polyphenolic compounds.

Chemically the tannins are divided in two main groups: the hydrolyzable extracts and the condensable extracts.

It is particularly the latter group which interests us since only the tannins form a satisfactory raw material for binding resins.

A considerable amount of work was done by Narayanamurthi (8, 9, 10, 11) in India, and Plomley (12, 13) in Australia, on the use of tannin extracts as the basic raw material for a wood binding resin.

Actually all their work was directed towards the manufacturing of plywood, however there is no fundamental difference between the gluing of plywood and the gluing of the particles in particle board, and although the gluing in particle board is more critical, the step from the one to the other can be done without too many problems.

Nico and Cremaschi (24) produced particle board from wood and flax shives with quebracho-formaldehyde binder while Rongel (15) produced bagasse particle board with the same binding system. Both achieved satisfactory results.

We ourselves have been working with quebracho as well as mimosa (black wattle) extracts on wood, flax shives and bagasse.

With the necessary technological adaptations, all these materials give boards comparable in quality to those obtained with the conventional urea-formaldehyde resins. It may even be expected that their aging properties will be superior as the basic constituent is of the phenolic type.

To facilitate the use of tannin extract binders or to overcome some of the technological problems it may, in some cases, be interesting to use a resin composition where synthetic resins and tannin extracts are combined. Both phenolic type resins or urea-formaldehyde resins can be used in combination with the tannin extracts if a proper catalyst is chosen. Some typical test results obtained with bagasse and a mimosa extract alone and in combination with a urea-formaldehyde resin are given in table VI below.

TABLE VI

	UF	UF/TF 20/80	UF/TF 10/90	TF
density kg/m3	602	607	604	607
modulus of rupture kg/cm2	211	213	207	214
modulus of elasticity kg/cm2	16,800	17,650	17,150	17,250
internal bond kg/cm2	4.92	4.31	4.44	4.55
swelling 10 x 10 cm after 24 hrs (%)	3.93	4.21	4.69	5.38
swelling 2,5x2,5 cm after 2 hrs (%)	4.08	4.23	4.17	5.30
internal bond after 2 hrs boiling water - kg/cm2	0	1.96	2.00	2.12
free formaldehyde (%)	0.2	0.135	0.127	0.135

UF: urea-formaldehyde resin;
TF: tannin-formaldehyde resin,
UF/TF: mixture of urea and tannin-formaldehyde resins.

It is obvious from these results that very satisfactory boards can be produced with tannin extracts as a basic raw material for the binding resin. The qualities obtainable as well as the technological production details have to be examined in detail, they should be the subject of a thorough preliminary study. The same applies to the economical facts. It is only in countries where tannin extracts are produced locally and synthetic resins still have to be imported that their use is economically feasible.

5. PREFABRICATED HOUSES FROM PARTICLE BOARD

From the very beginning of flaxboard production considerable efforts were made to introduce this board into the building industry. It was initially used as a replacement for other conventional materials, but very soon its specific applications were found for it, where its particular qualities were valuable.

However, if particle board simply replaces natural wood or plywood in the furniture industry without the fundamental principles being changed, this was not so in the building industry.

A completely new approach was necessary, this was one of the reasons why besides successes, failures were also noted. The different applications of any type of particle board in the building industry have to be the subject of careful study. The rules to be applied for the use of particle board are no different from the general rules for any type of building material, but they have to be applied with more strictness, as the consequences of not following these rules may be much worse. A particle board is a material sensitive to moisture. One of the critical points for its application is for example moisture transmission in an exterior wall. This phenomenon is known and occurs in nearly all building materials. If a wall has been properly conceived according to the surrounding conditions, both interior and exterior, no problems will result. But if for example a particle board is used as the core of an exterior wall element, and on the outside of this element a completely water-vapour-proof barrier is applied (metal plates, glass, etc.), while on the inside a normal porous surfacing material is used (paint, asbestos-cement sheeting, wood, etc.) it is certain that at a given stage the moisture (water vapour) accumulating between the interior and the exterior surfaces will exceed the saturation value of the board and the vapour will condense and form (liquid) water. This process can be considerably accelerated by temperature differences (surfaces exposed to the sun during the day and cooling at night). As the board itself is not absolutely water resistant it will become degraded, it swells and after a certain time delamination of the surfacing materials may occur. Furthermore, the presence of excess moisture highly activates the development of micro-organisms which destroy the board even more quickly. Such problems, though, are easy to avoid by applying the general rules for wall construction and by using the correct surfacing materials.

For satisfactory application of the board, the problem is to use the right combination of materials and techniques, rather than a particular type of board, yet a board of improved quality may allow better solutions at a lower over-all cost.

Although failures have been observed, the use of particle board for building purposes has increased tremendously and from nearly nothing some ten years ago the building industry now absorbs over 35 % of the total board production and in some countries even up to 75 % (16).

Particularly successful applications are: roof coverings, roof linings, door cores, interior partitions, curtain wall elements and ceilings.

Figures 12 and 15 illustrate some typical applications of flaxboard in the building industry.

Taking into account the foregoing chapters and the above considerations, a logical integral addition to a particle board plant is a specialised workshop for the manufacturing of prefabricated houses. Such a workshop essentially consists of woodworking machinery, and allows with the aid of a few skilled carpenters the production of structural building elements of any type. These elements are light, easily transportable and quickly assembled. Boards with adequate surfacing allow the realization of very simple, low-cost rural houses as well as the execution of luxuriously finished multi-storey buildings.

The principal interest of an integrated prefabricated house manufacturing unit for developing countries however remains the production of low-cost houses.

It is possible to manufacture a prefabricated house of about 60 m2 for no more than US$ 2,000, this sort of complete house can be easily transported by a 3-ton truck, even over difficult roads to places not accessible with heavy equipment. On a properly prepared site the house can be erected by a team of 5 to 6 men within 5 to 10 days. By grouping the erection of several houses on the same site, a lot of time can still be saved.

Investments for a prefabricated house manufacturing unit

A unit with a production capacity of 10 to 20 houses per day, integrated to a particle board plant requires an investment of approximately US$ 300,000, consisting of approximately US$ 250,000 for machinery while the rest is essentially for the workshops The integration of the house manufacturing unit to the board plant will keep the over-all costs low, as it saves costs for board transportation and limits the investment to the essential machinery, while the auxiliary equipment of the particle board plant such as a boiler, electrical equipment, air compressor, etc. can be used for both units.

6. PARTICLE BOARD FINISHING

A second highly justified supplement to a particle board plant is a board finishing department.

Particle board lends itself very well to a multitude of different types of surfacings and these broaden the field of application of the board.

Several surfacing materials require a very specific application equipment. From this point of view two main groups may be considered:

(1) products which exist already in sheet or film form, to be applied by presses;

(2) liquid products to be applied by coating machines.

In each of these two main groups several products are to be found with very varied properties, which also require specific conditions and equipment for their application.

A compromise must therefore be accepted, allowing the maximum possible variety of surfacings for a minimum investment, covering as much as possible of the market.

The most usual types of surfacing are:

(a) Veneering with natural wood

Both peeled and sliced veneers are used extensively on particle board both for the furniture industry and in the building industry. The difference is that most furniture plants have their own veneering presses, and will only buy the unfinished boards.

(b) Application of plastic films

The plastic films are glued on to the particle board. Generally the films are based on polyvinyl chloride, polystyrene or polyester. They are coloured and may be printed with all types of patterns. Wood imitation is most in favour.

This type of surfacing is particularly suitable for kitchen cabinets, wall panelling and large series of cheaper furniture.

(c) Application of laminates

Glued on both sides of the board they provide the board with hard working surfaces, rigidity and stability. Laminates are essentially pressed phenolic- and melamine-resin-impregnated papers or reinforced polyesters. They are rather expensive and serve more the luxury or high quality demands.

(d) Application of asbestos-cement sheets

As for the laminates, these sheets are glued on both sides of the board especially for exterior wall elements.

(e) Application of papers

Various types of paper, some impregnated with resins, may be directly pressed or glued on the boards. According to the type of paper the most diverse applications are possible.

(f) Coating

The application of a basic coat acting simultaneously as a pore-filler, primer and sealer is very interesting for boards in the building industry.

Such a board can be easily finished with one layer of paint, and in the case of industrial buildings, the coated board does not need any supplementary finishing.

(g) Lacquering

To lacquer a particle board, the surface of the board must be of excellent quality and even then the complete system - filler, sealer, first coat and second coat - must be very well studied to obtain satisfactory results. A better result is obtained by combining the application of a resin-impregnated paper as a basic layer and then applying the lacquer.

(h) Printing

One of the newer finishing systems is a direct printing of any pattern, but usually a wood imitation, on the board. Here again, to obtain satisfactory results, a board with a perfect surface quality is necessary. As such boards are not always available, a better solution consists in the application of a cheap thin veneer on the board and the printing of a wood of a more expensive pattern on the veneer.

Although the products manufactured are cheap, printing requires rather high investment.

As said before a compromise must be accepted, and experience has taught us that one of the optimum solutions is the installation of a surfacing press with the necessary secondary equipment such as a veneer cutting and jointing machine, a glue coater, a saw, a sanding machine, etc. and a coating line.

The surfacing press allows the application of most of the surfacing materials available in sheet or film form while the coating line gives a board ready to be painted for all interior uses in houses and even sufficient to be used without supplementary finishing for industrial buildings. These two types of equipment together will certainly cover a very large percentage of the possible demands for surfaced boards.

The machinery cost for the press unit is approximately US$ 150,000 while it is approximately US$ 60,000 for a coating unit. It is needless to add that the costs vary proportionally with the production capacity. The above figures are based on board production units of 30 to 60 tons per day, considering that 50 to 75 % of the boards are surfaced.

7 CONCLUSIONS

Most of the annual plant wastes provide very valuable raw material for the manufacture of particle board It has been proved on an industrial scale that first-class boards can be produced from bagasse cotton stalks, flax shives, hemp and jute.

Several annual plant wastes have the advantage over wood that they permit the production of low density boards, particularly useful for insulating purposes.

Experience has proved that boards from annual plants are at least as valuable as wood particle boards in the furniture industry, and even more valuable in the building industry

Laboratory tests followed by industrial testing and production have proved that phenolic resin bonded boards (exterior type) can be made with annual plant wastes of the same quality as wood, or better.

The utilization of certain natural products, such as tannin extracts, as a binder for particle board is possible, and gives a board of very satisfactory quality. Inspectors and experts should also consider this side of the problem

A particle board factory can usefully be complemented by a board finishing and surfacing unit and in several cases, especially in developing countries, by a prefabricated house manufacturing unit. Complementary investigations and research work could considerably increase the number of annual plant wastes suitable for the manufacture of particle board.

The actual board production processes from annual plant wastes are not so very different from the processes for wood board production but a perfect knowledge of the raw material is necessary to set up a correct flow sheet avoiding all hazards and eventual failures.

There is no need to make a clear distinction between particle board made from wood and particle board made from annual plant waste.

All distinctions made should be based on board qualities rather than on raw materials used.

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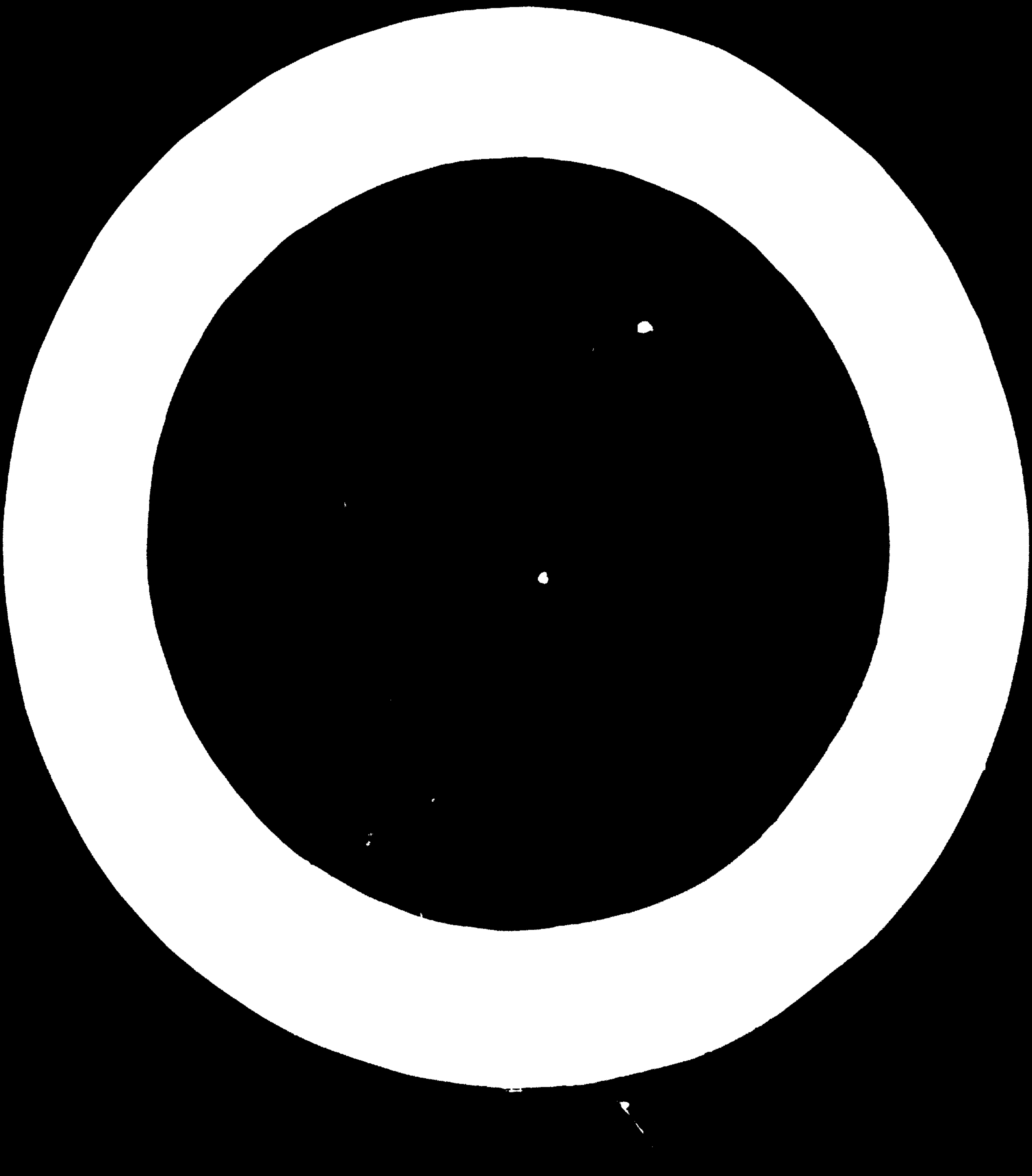


BAGASSE.

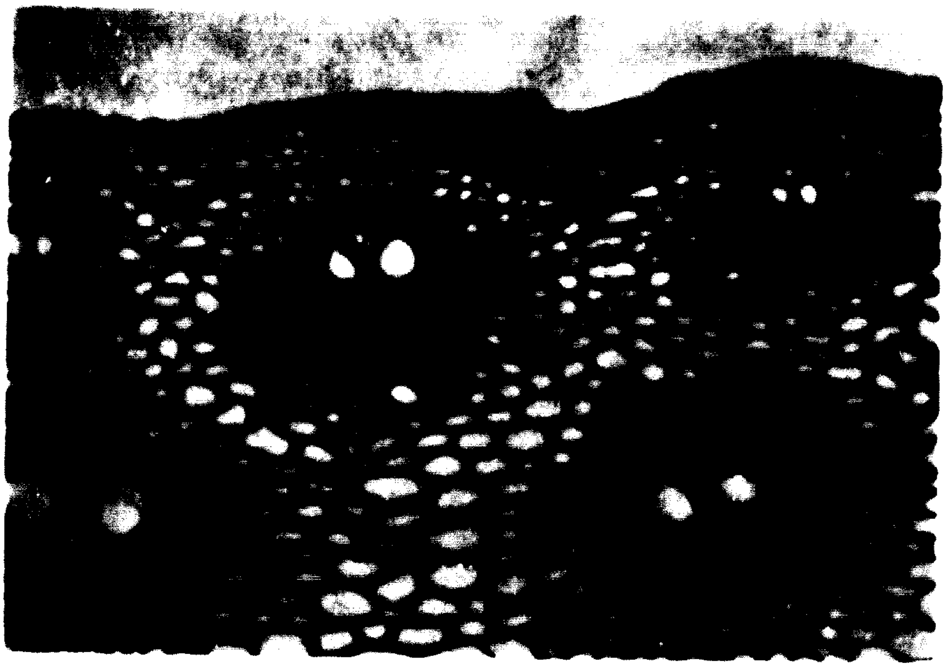


fig. 1.
x50.
crosscut.

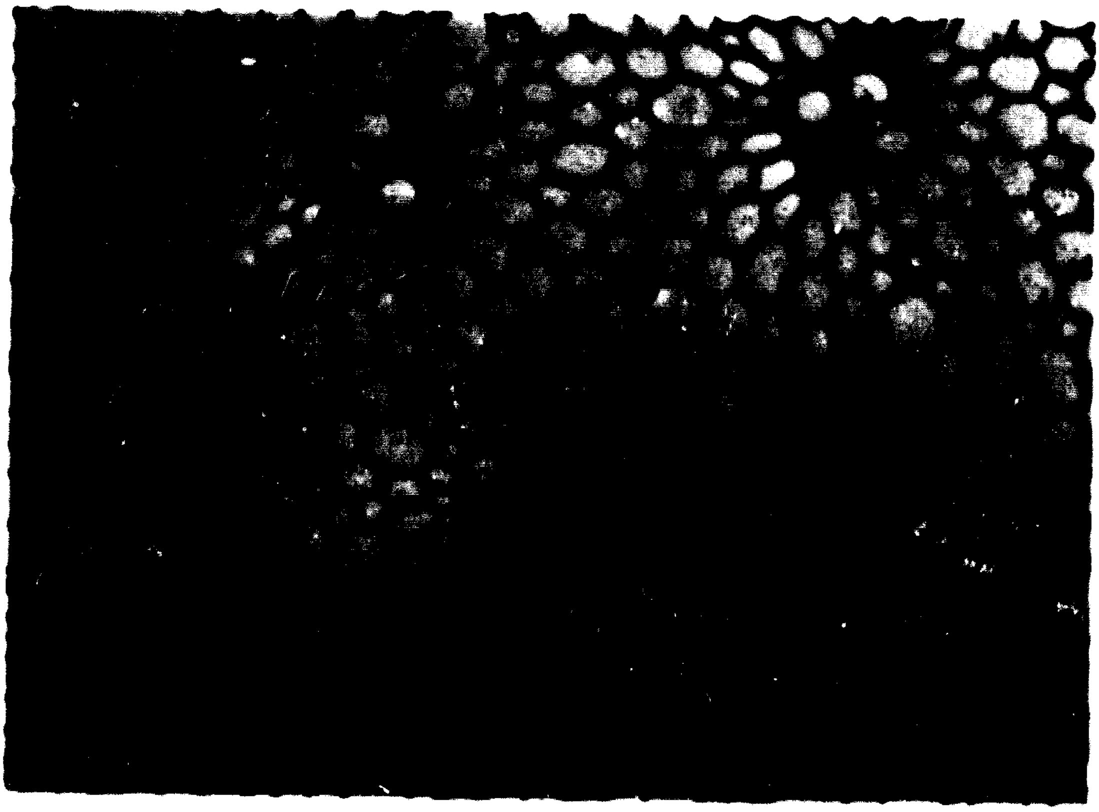
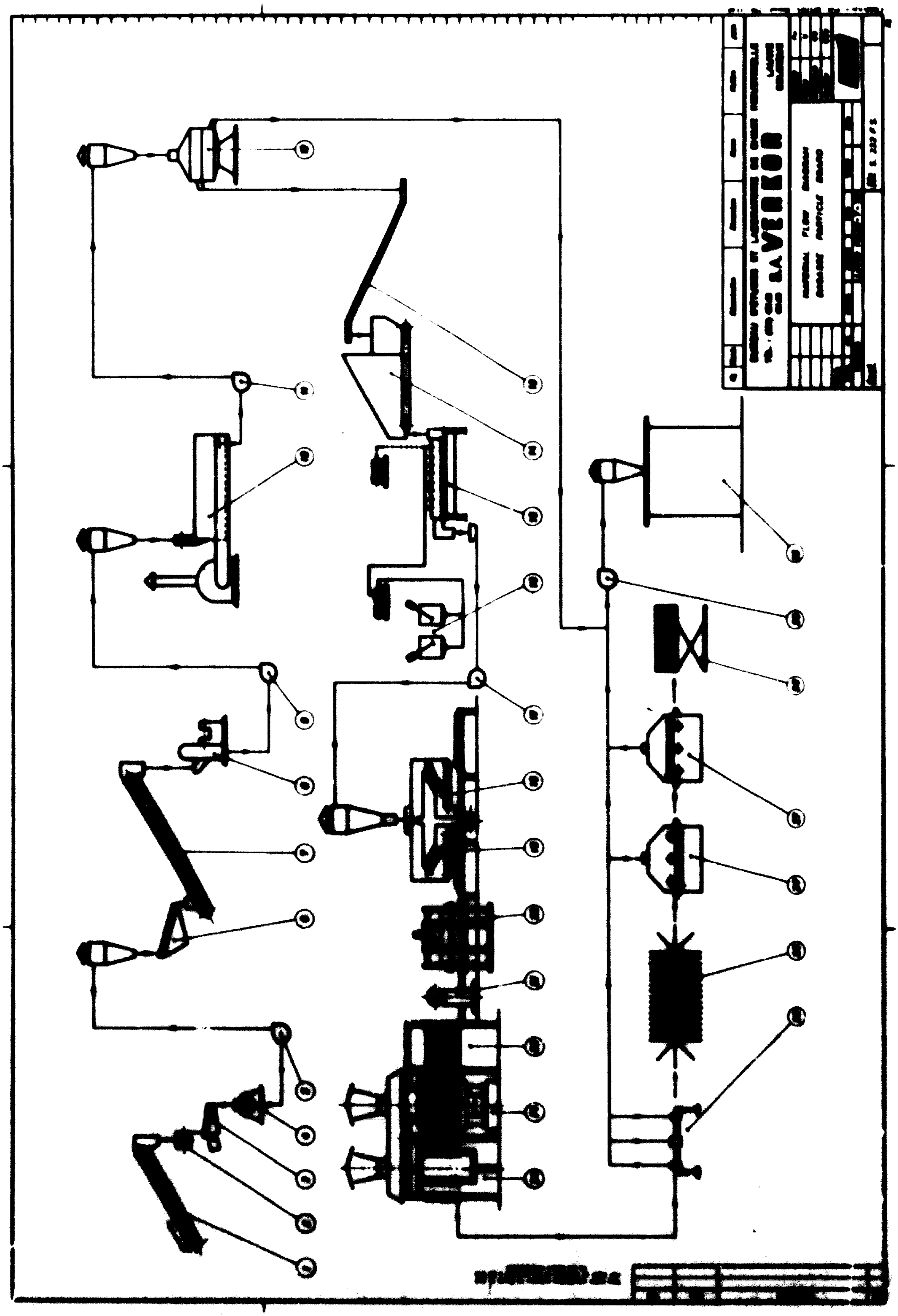


fig. 2.
x50
crosscut.

Figure 3



FLAX.

fig. 4.
x70.
crosscut.

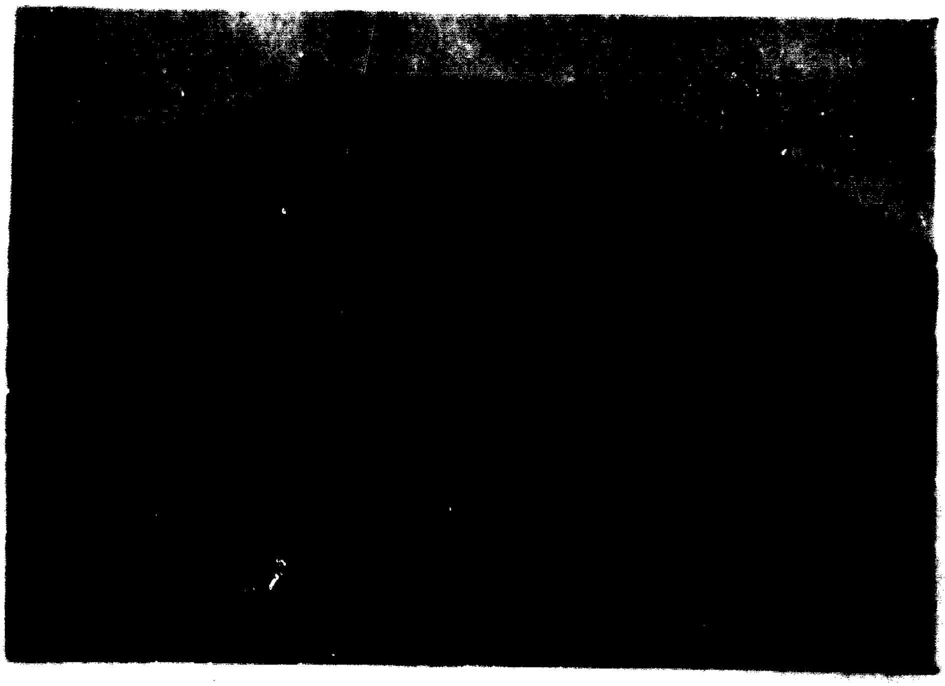
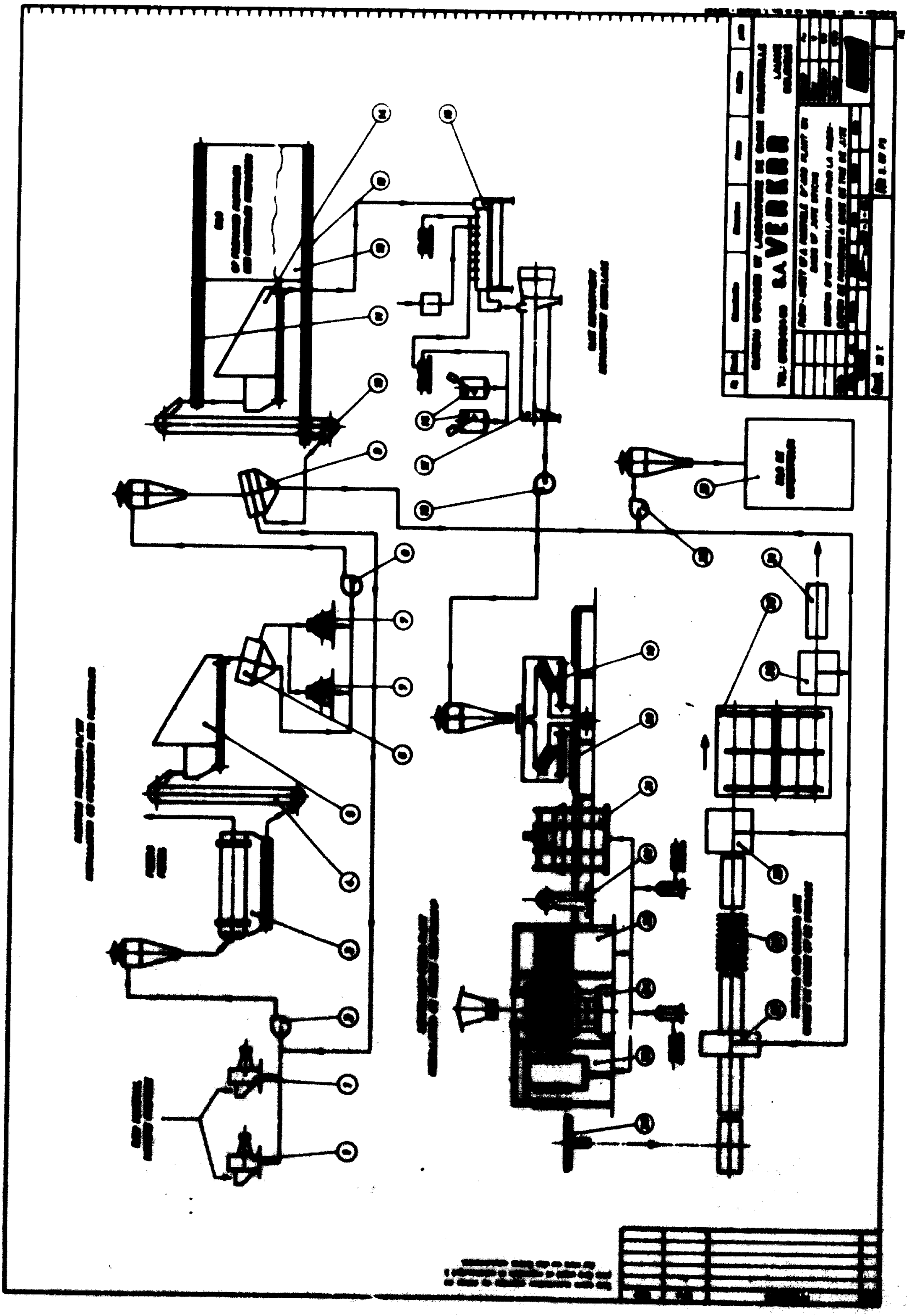


fig. 5.
x100
crosscut.

Figure 6



PEANUT.

fig. 7.
x70.
crosscut.

RICE HULLS.

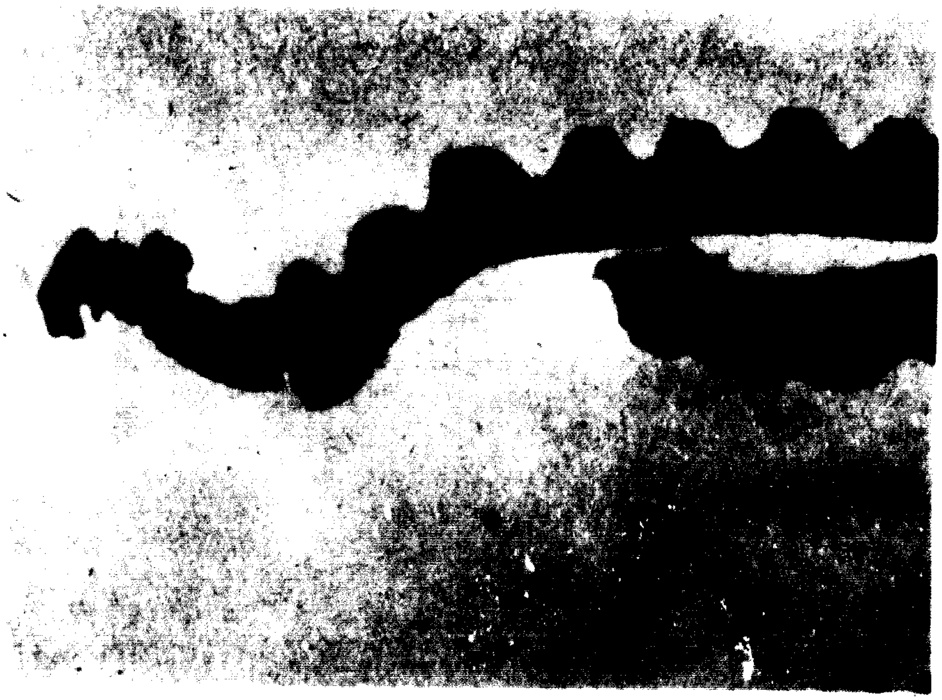


fig. 8.
± 70x
crosscut.

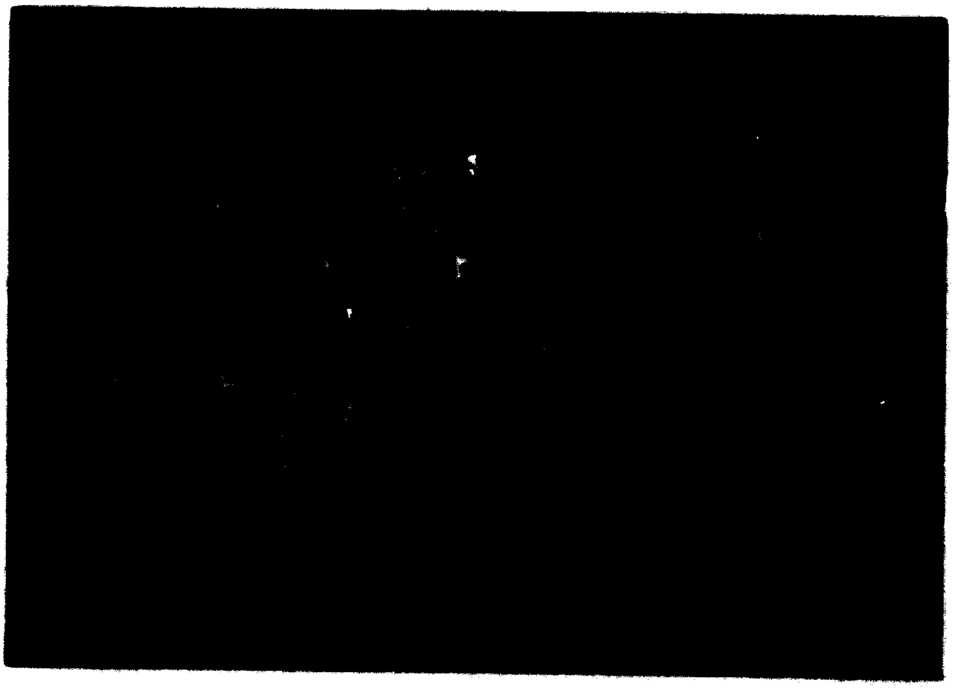


fig. 9.
x30.
surface macrophotographie.

MAIZE.

fig. 10.
x150.
crosscut.

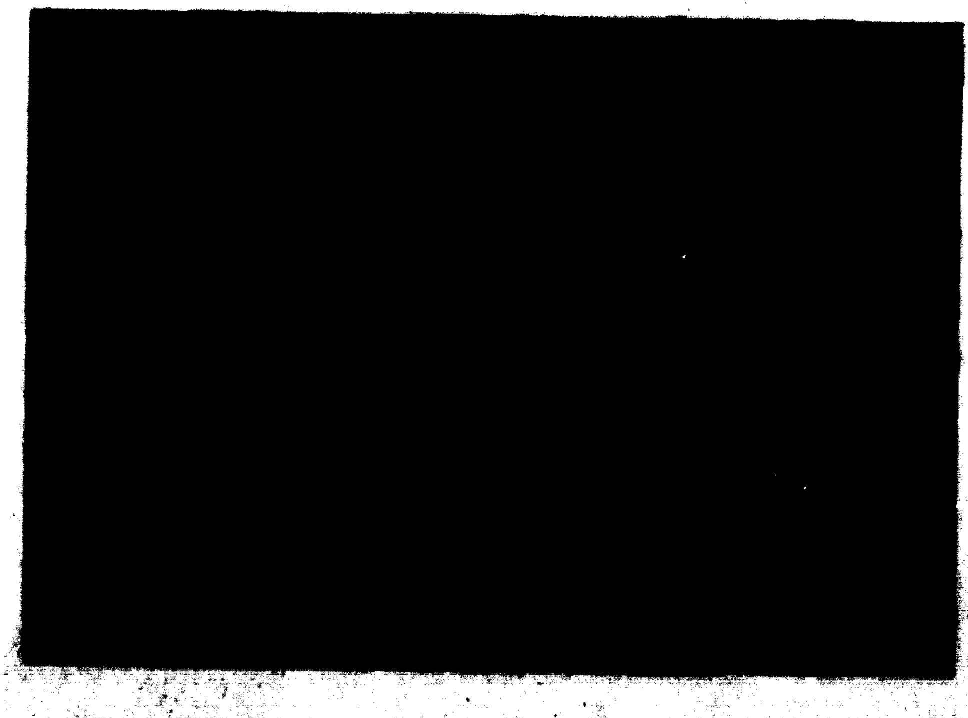


fig. 11.
x[illegible].
crosscut.

fig. 12.

prefabricated type school pavilions (1958).

fig. 13.

prefabricated wall elements.

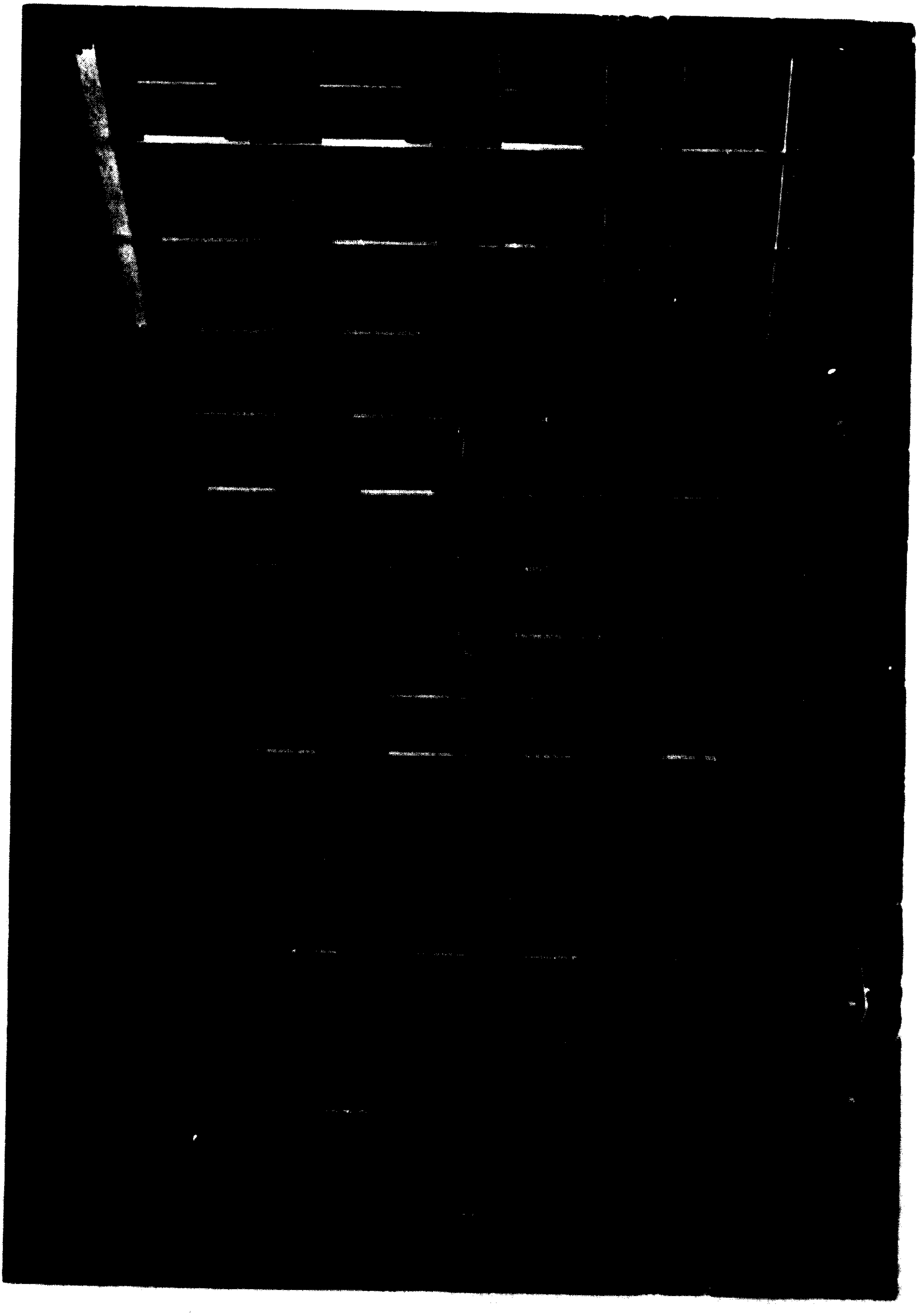


fig. 14.
interior partition and ceilings.

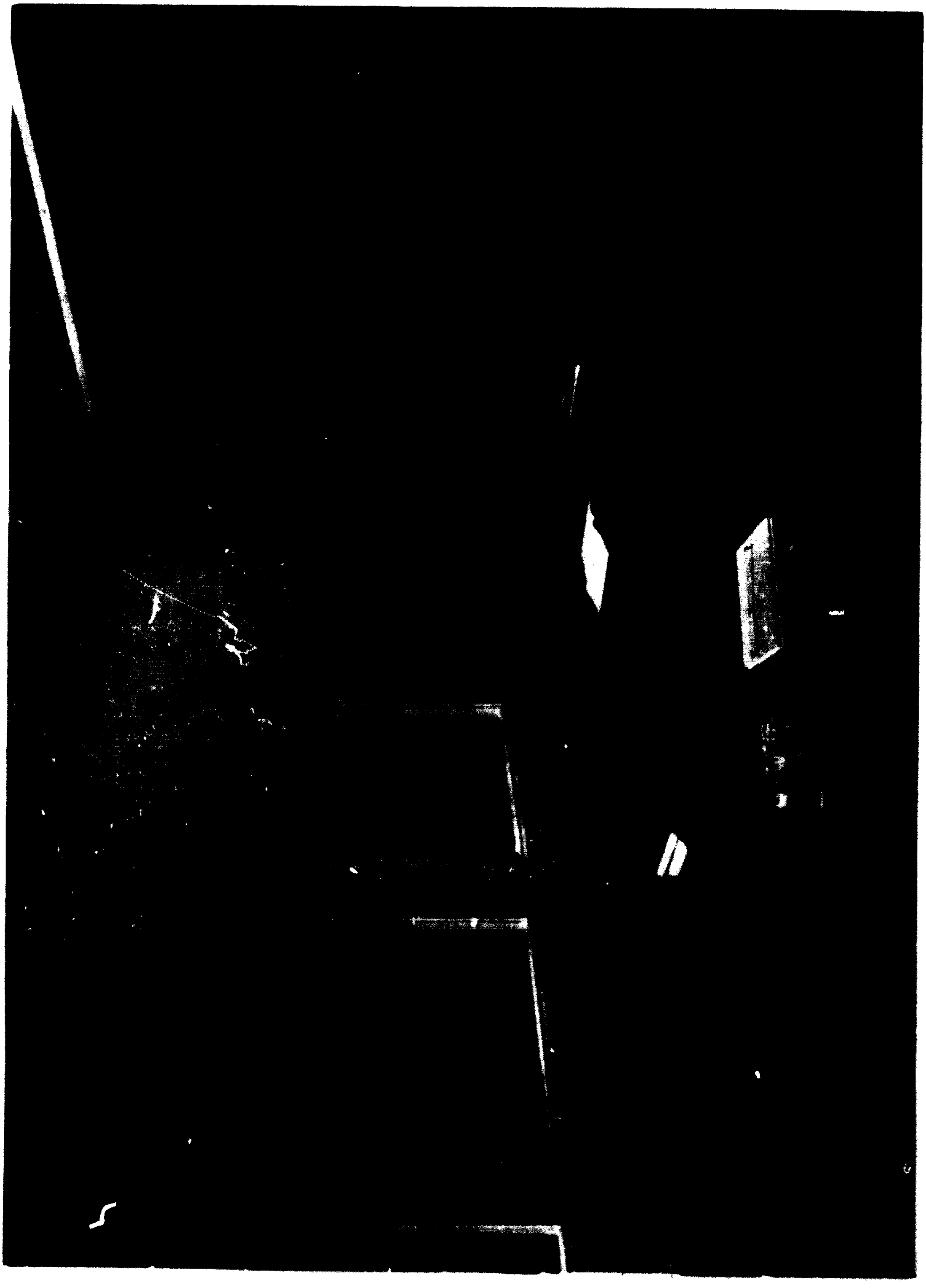
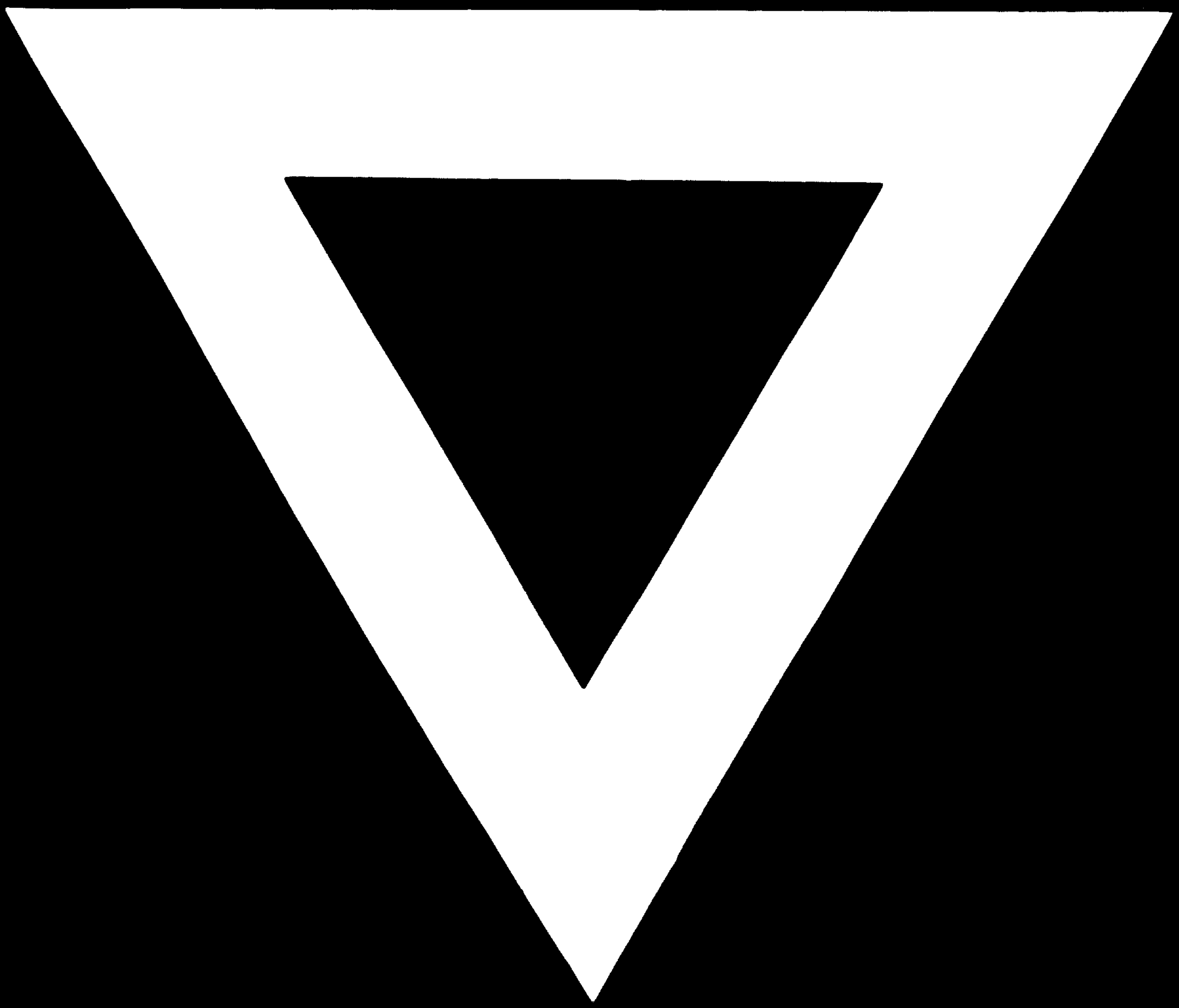


fig. 15.

exterior wall elements and
interior partitions.
(Shape buildings in Casteau).



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