THE SUITABILITY OF COTTON STALKS FOR THE PRODUCTION OF MEDIUM DENSITY FIBREBOARD

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SUMMARY

The medium Density Fibreboard is dry formed panel and is usually produced from lignocellulosic fibre bonded with resins. It is made from wood fibres. The purpose of this project is to investigate the suitability of cotton stalks for the production of such boards.

The cotton stalks consist of the pith which is the soft central portion of the stem, the wood blast which is the main part of the stem, the cambium which is the lignocellulose layers and the bark,

A laboratory samples were produced from cotton stalks. The process was chipping, sifting, washing, cooking, defibration, drying, and second defibration, resin blending, mat forming, pressing,trimming and conditioning.

The produced samples were tested for evaluation of the physical and mechanical properties. These tests were bending strength, tensile strength parallel to surface, tensile strength perpendicular to the surface, compression, nail resistance, screw withdrawal, surface soundness, water absorption and thickness swell tests.

The test results were compared with the data available from the present standards. All samples

passed all the tests successfully except for water absorption and thickness swell tests because no wax was added during the process of manufacturing the samples. But in general, the results proved that the cotton stalk is good material for MDF making.

It is recommended strongly that a MDF Plant, based on the cotton stalks as raw material, be established.

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C O N T E N T S

	Page
SUMMARY	i
ACKNOWLEDGEMENTS	iii
INTRODUCTION	1
1 - THE MEDIUM DENSITY FIBRE BOARD ..	3
1.1. Definition	3
1.2. Basic Process in the Manufacturing of MDF	3
1.3. Origin and Development of MDF Plants	4
1.4. Spread of MDF Manufacturing Plants	5
1.5. Uses of MDF	5
2 - COTTON STALKS	7
2.1. The Cotton Plant	7
2.2. Cotton Production in Nigeria..	7
2.3. Cotton Stalks	9
3 - LABORATORY PRODUCTION OF MEDIUM DENSITY FIBREBOARD FROM COTTON STALKS ..	11
3.1. Process and Equipment ..	11
3.2. Chips Production	11
3.3. Sifting	12
3.4. Washing	12
3.5. Cooking	12
3.6. Defibration	13
3.7. Drying and Second Defibration	13

		Page
3.8.	Resin and Resin Blanding ..	14
3.9.	Mat Forming	15
3.10.	Pressing	16
3.11.	Conditioning	17
3.12.	Process Flow Chart	17
3.13	The Specimens	18
4 - TESTS OF THE MDF SPECIMENS		19
4.1.	Determination of Density ..	19
4.2.	Bending Strength Test ..	20
4.3.	Tensile Strength Test Parallel to Surface	21
4.4.	Tensile Strength Perpendicular to to the Surface	22
4.5.	Compression Strength Parallel to Surface Test	22
4.6.	Nail Resistance Test	23
4.7.	Screw Withdrawal Test ..	24
4.8.	Surface Soundness	25
4.9.	Water Absorption and Thickness Swell Test	25
4.10.	Moisture Content Test ..	26
5 - DISCUSSION OF TEST RESULTS		28
5.1.	Density	30
5.2.	Bending Strength	31

Page

5.3. Tensile Strength 32

5.4. Compressive Strength 32

5.5. Nail Push-Through and Screw Withdrawal 33

5.6. Thickness Swell 33

5.7. Water Absorption 34

5.8. Moisture Content 35

6 - CONCLUSION OF THE DISCUSSION OF RESULTS 36

7 - RECOMMENDATIONS 38

8 - REFERENCES 39

9 - NOMENCLATURE 42

10 - APPENDIX I: Industrial Production of MDF 45

11 - APPENDIX II: Sample Calculations .. 49

12- PLATES 51

INTRODUCTION

The cotton stalk has been used successfully for the production of particle board. There are several plants in various country using cotton stalks as the main raw material for their production. With the fast spreading of MDF Board Production Plants which so far are using mainly various types of wood wastes, and as it is known that the MDF board has more advantages over particle board, it is worth the trouble to investigate the suitability of cotton stalks for MDF board production; especially that there are large quantities of cotton stalks available in in the Northern States of Nigeria which are more or less useless at present. It is even recommended to get rid of them before the plantation of new crops in order to avoid infection. Cutting and burning the cotton stalks cost some money, effort and time to the farmer; but if it could be utilized for something useful as board manufacturing, it would no longer be called agricultural wastes but useful raw material for board industry, and that will add,beside financial advantages to the farmer, economic growth to the nation; and increased plantation of cotton. For this reason, investigation was carried out to determine the suitability of cotton stalks for

MDF Board production.

This report will first introduce the MDF Boards, then the cotton stalks and finally the production of laboratory samples with test results.

1 - THE MEDIUM DENSITY FIBRE-BOARD

Medium density fibreboard was started about a decade ago. It is therefore needful to start this report by defining and introducing the MDF Board.

1.1. DEFINITION:

Medium Density Fibreboard (MDF) is defined as dry formed panel product manufactured from lignocellulosic fibre bonded with Urea formaldehyde and Urea melamine formaldehyde resins and/or additives may be added. It is usually flat pressed but may be moulded. It is manufactured within density range of 400 to 925 kg/m^3, and is principally used in the manufacture of furniture and related products.

At present, it is made principally from wood chips, but work is under way in many research centres for the use of cheaper raw materials.

1.2. BASIC PROCESSES IN THE MANUFACTURING OF MDF:

The manufacture of MDF starts from the production of chips from the raw material such as hard or soft wood mill wastes, foresting waste or agricultural waste. The chips are then charged through a rotary valve of plug feeder into a steam pressurized vessel where they are softened at pressure of 5 - 10 bar and 160^{o} - $180^{o}C$ temperature in a period of just a

few minutes. The chips are next fibrized in a refiner and dried to 5 -6% moisture content and treated with 8 - 12% resin solids. Wax may be added to meet water soak requirements.

Fibres are next formed into mats by multiple head, free-fall vacuum formers and prepressed cut-to-length and pressed to required thickness between two hot plates. In RF (radio frequency) process supplementry heating is done by high frequency electric power. The boards are then trimmed and conditioned for about a day.

1.3. ORIGIN AND DEVELOPMENT OF MDF PLANTS:

MDF production started in Virginia, U.S.A. in 1966 by Miller-Hoft Engineering under Barnett Division of Alied Chemical Corporation. Soon afterwards, other plants came up in Japan, East Germany, Yugoslavia, Spain and New Zealand.

During the period from 1966 - 1969, the process and equipment difficulties associated with its development and sales promotion were solved.

Development of market for MDF actually started in 1968. At that time the cost of using MDF in a three-ply wood veneer construction of which the edges are machined was ₦1.00 - ₦1.40 per square metre less than solid wood core or five-ply, rimmed particle board.

1.4. SPREAD OF MDF MANUFACTURING PLANTS:

Report on the spread of MDF manufacturing plants is available for the United States with only little reference to the other countries. This discussion is therefore narrowed to the available report.

Between 1970 and 1972, four plants commenced production of MDF with capacities of 120,000 - 140,000 cubic metres per year. These were based on either the hot press process or the radio frequency process. Between 1974 and 1976, five more plants were built in the United States and two in Europe - Krivaja at Busavaca, Yugoslavia and Intamasa at Teruel, Spain.

In 1976, another plant was built in New-Zealand. This plant was the first to successfully use refiner blow line addition of resins and press control system for controlling board thickness and density distribution.

By 1978, production in the United States rose from 20,000 in 1967 to 975,000 cubic metres per year. About 15% of the present production of MDF are 9.5 mm or less 25% from 10 - 19 mm and 10% above 19 mm thickness.

1.5. USES OF MDF:

MDF is used mainly in the furniture and building industry. It is thereby replacing particle board and wood components.

Particle board is made from wood pieces called semi-flakes or particles. Its density therefore depends on that of the wood species. Hence MDF is superior to particle board in edge quality, paintability, machinability and product uniformity.

It is used in the making of cabinets, wall panels, floor underlayment, table edges, shelves, doors, drawers and many other areas which require decorative carving. In summary, MDF is noted for its uniformity, absence of surface defects, narrow geometric tolerance, strength and dimensional stability.

At the moment, MDF is made from wood mainly, same as plywood and particle board. The high quality of MDF and its high production cost does not appreciate high raw material cost. Hence, cheaper raw materials must be sought for to substitute wood.

Agricultural wastes including cotton stalks have been successfully used for particle board making. Similarly, MDF can also use agricultural wastes when it has been proved to be of high quality.

2 - COTTON STALKS

2.1. THE COTTON PLANT:

Cotton is one of the oldest crops cultivated by man. It grows in the tropical and sub-tropical areas. It belongs to the group of mallow plants and can grow as herb and also as bush. There are many different classes and species that reach heights of up to 2 metres. But cultivated cotton normally grows to 0.9 - 1.2 metres only. It is mostly seasonal plant but may become perennial.

Cotton is grown mainly for its lint and seeds. The lint has been used to make cloth since 3,000 B.C. and even earlier. Most of the Ancient Empires used cotton cloth. The seeds have been used for oil and livestock feed. The yield of cotton lint per acre is about 5,500 kg. on average, but the yield may be up to 6,600 kg/acre. After the harvest of cotton lint, the clearing of the stalks remains a problem.

2.2. COTTON PRODUCTION IN NIGERIA:

Cotton has been grown and used for spinning purposes and weaving in Nigeria for hundreds of years. There are records of brief exports of cotton around the time of the American Civil War. But the modern industry did not begin to take shape in Nigeria until the first decade of the 20th Century.

Cotton was first introduced in Lagos Colony, and soon expanded to Ibadan area (former Western Region) and from the present Western States (Oyo, Ogun, Ondo), it was pushed up country as far as transportation permitted; first along river routes, then to farther distances as railroads became available. At times it advanced ahead of the railroads in the expectation that opening an area to cash cropping would help induce expansion of the railroad.

This was demonstrated to a degree with the railroads reaching Gusau in 1928. As early as 1910, however, following the completion of the Baro-Kano rail line to Zaria, a ginnery powered by cotton seed-generated gas, was erected at Zaria to serve a wide area of the North. Cotton grown in the north was whiter than that of Lagos Colony and graded "excellent" in quality. An additional reason for moving the industry to the north, apart from uncertainty of rains in the south which frequently interfered with harvesting of cotton as well as causing damage to the harvested cotton, was the greater competition in the south for land and labour which unused resources were apparently more readily available throughout the north.

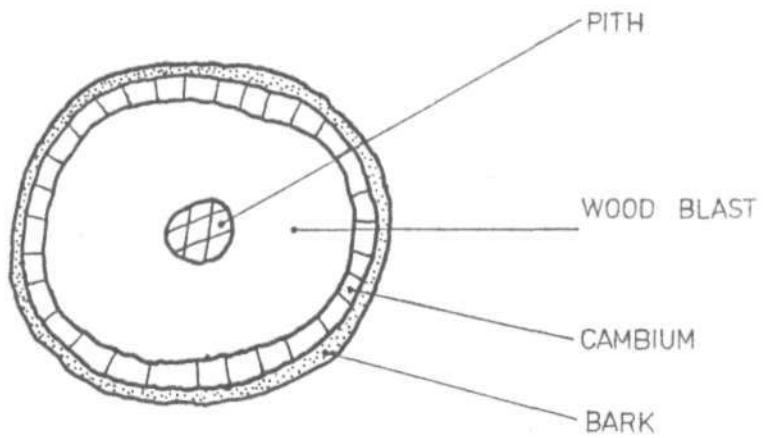


FIG.(1) CROSS-SECTION OF THE COTTON STALK

2.3. COTTON STALKS:

Cotton stalks which are now our interest, are the stems of the cotton plant which are left behind when the lint has been harvested and the leaves have dried up and fallen off. Chopping out these stalks from a farm is not an easy process; they are strong and not easily broken by ploughing impliments. Small growers have to use heavy hoes to chop them off, collect and burn them on government order, for pest control and to clear the farm for the next planting season. If the stalks are not cut, the plant may start to grow again at the approach of the next planting season. Cotton easily becomes perennial.

The stalks consist of four main portions: the pith, wood, cambium lingo-cellulose layer, and bark.

The proportion of these components vary, depending on growing condition, class, species, soil structure and harvest conditions.

(a) THE PITH:

This is the soft central portion of the stem. It easily becomes powder during chipping. Its proportion increases from about zero at the root to 80% at the tip of the plant. But the length of the tip which has high pith content is very small. It can be used together with the other parts for board making.

(b) WOOD-BLAST:

This is the main part and consists of a woody layer. Its proportion decreases from 80% at the root to 10% near the branch tip. It is very good for making of fibres.

(c) CAMBIUM:

This is the ligno-cellulose layer. It is very fibrous and the best for making of fibres. But its proportion is very small; from 17% at the root to 3% at the tip of the plant.

(d) BARK OR CORTICAL LAYER:

This is composed of dried cells and a thin inner layer. It is reddish brown in colour and not good for board making. Its proportion increases from 3% at the root to 7% at the tip. It reduces board strength and binding properties. But since its proportion is very small and it is hard to separate from the cambium layer, it is usually ignored. But where higher quality board is required, it can be removed during soaking. It soaks and sinks easily in water

3 - LABORATORY PRODUCTION OF MEDIUM DENSITY FIBREBOARD FROM COTTON STALKS

3.1. PROCESS AND EQUIPMENT:

The cotton stalks used for the manufacture of MDF were collected from the Ahmadu Bello University Farm. The production of MDF was carried out by using the available laboratory equipment. The industrial production of MDF is explained in Appendix II.

The process followed for the production of the MDF from cotton stalks is as described below.

3.2. CHIPS PRODUCTION:

The process of manufacture begins with the production of chips. The cotton stalks collected from the University farm were cut by employing a knife-edge flaker. In order to have a knowledge of the sizes of the chips produced and hence determine the amount of wasted chips, a sifting analysis was carried out. This analysis gave the following result.

GRADE	% BY WEIGHT
Over 1.7 mm	49.4
1.06 - 1.7 mm	20.8
710 Um - 1.0 mm	9.6
365 Um - 710 Um	11.6
250 Um - 365 Um	3.8
150 Um - 250 Um	2.4
106 Um - 150 Um	0.8
Below 106 Um	1.6

The moisture content is 5.4%.

3.3. SIFTING:

The chips were sifted into three grades. The sieves used were the 0.710 mm and 1.7 mm grades. The first grade consists of chips of sizes less than 0.710 mm weighed about 20%. This grade consists of pitch and fines mainly. For this reason it was not used.
The second group of sizes from 0.710 - 1.70 mm and above weighed about 80%. This grade was wholly used.

3.4. WASHING:

The chips were soaked in water for a short period of time (less than 10 minutes). The basic reason for washing the chips is to remove the dust and sand particles and possibly foreign products; and small pieces of metals, etc. After soaking the chips for some time, all these products which sank to the bottom of the container were rejected and the floating chips and the suspended best fibres were collected. The soaking also increased the moisture content of the chips which was initially at 5.4% (oven dry basis).

3.5. COOKING (Softening):

Saturated steam boiler providing 5 - 10 bar pressure, and 160 - 180^{o}C temperature is required for industrial production. But since such boiler was not available, a pressure cooker of 5 litres liquid capacity was used.

The cooking temperature, pressure and time were 120°C, 2 bar, 20 - 30 minutes, respectively. As a result of the boiling process, hydrothermic melting of the lignin takes place. This means that not only the mechanical disintegration of the material is achieved but also the improvement of the fibre quality.

3.6. DEFIBRATION:

The process of defibration was carried out immediately after the cooking of the chips was completed. A disc grinder coupled to an electric motor was used for the defibration. The chips were ground while still hot and for every set of the grinding operation, an additional bucket of hot water was required. The hot water aided the easy flow-out of the defibred chips from the grinding disc gap. The excess water was removed at the end of each grinding by the use of a sieve and the fibres were then taken to the next stage.

3.7. DRYING AND SECOND DEFIBRATION:

The fibres obtained from the chips were found to have a moisture content of well over 100% (oven dry basis). Thus the necessary step after the defibration is the drying of the fibres. The wet fibres were spread on a zinc roof and dried for a whole day to a residual moisture content of about 5 - 8% (oven dry basis).

A second defibration was necessary since the dried fibres were found to form nodules, which can result in uneven distribution of the resin and the occurence of resin spots. This was done when all the components of the grinder were dry and clean from dirt.

3.8. RESIN AND RESIN BLENDING:

The resin used for the manufacture of the MDF is Urea-formaldehyde which is a thermosetting resin and this is the standard resin for both particleboards and fibreboards.

3.8.1. RESIN PREPARATION:

The resin used was Urea-formaldehyde. The equipment used were the refluxing unit, vacuum distillation unit, and a chemical balance. The composition of the resin is given as follows:-

Urea-formaldehyde UFC	60%
Hardener(Ammonium Chloride)	1%
Ammonia	1%
Water	38%
Total	100%

The liquid resin obtained has a solid content of 50% Ammonia and ammonium chloride were also mixed with U.F.C. together with some water at normal room temperature to form the binder. The resin was used on the day of preparation in order to avoid possible contamination

if kept for some time.

3.8.2. RESIN BLENDING:-

Blending of the resin and fibre was done with the aid of a compressed air sprayer. The fibres were contained in a plastic bucket, and the jet of compressed air-resin directed towards it. The sprayer gun was held very close to the bucket in order to minimize the amount of resin lost to the atmosphere. To achieve uniform blending, it was necessary to agitate the fibres. This was done manually and also by the action of the air pressure from the sprayer. The quantity of the resin used was 11% of the weight of the dry fibre. This resin was added to give the board the desired strength properties since the board properties do not rely on the natural wood resins.

3.9. MAT FORMING:

The forming mould was produced in the workshop. The mould is a square wooden box (200 mm x 200 mm x 40 mm) and 2 stainless steel plates. The square box was placed on one of the stainless steel plates and the resin blended fibres were introduced in the cavity by hand. After a weighed quantity was fully introduced, the fibres were carefully pressed with the aid of a wooden block to aid easy removal of the mould box. The mould box was removed and a second stainless steel plate placed on top of the

mat. The dimensions of the plate were slightly larger than the mat formed in order to cater for the loss at the sides.

3.10. PRESSING:

The formed mat was taken to the hot press. The press used is a hydraulic pressing machine. This machine is fitted with a temperature and pressure indicating devices and a timer - and it has the following specifications:-

Temperature limit	200°C
Maximum pressure	483.84 bar
Voltage	230V at 50 Hz
Plate size	215 mm x 215 mm

3.10.1. PRE-PRESSING:-

The plates were heated to a temperature of about 70 = 80°C and the mat was introduced and pressed at this temperature to a pressure lower than that required for the actual pressing. The pressed mat was allowed to stay at this temperature and pressure for about one minute after which the pressure was released. This pre-pressing was necessary in order to remove the trapped gases and steam.

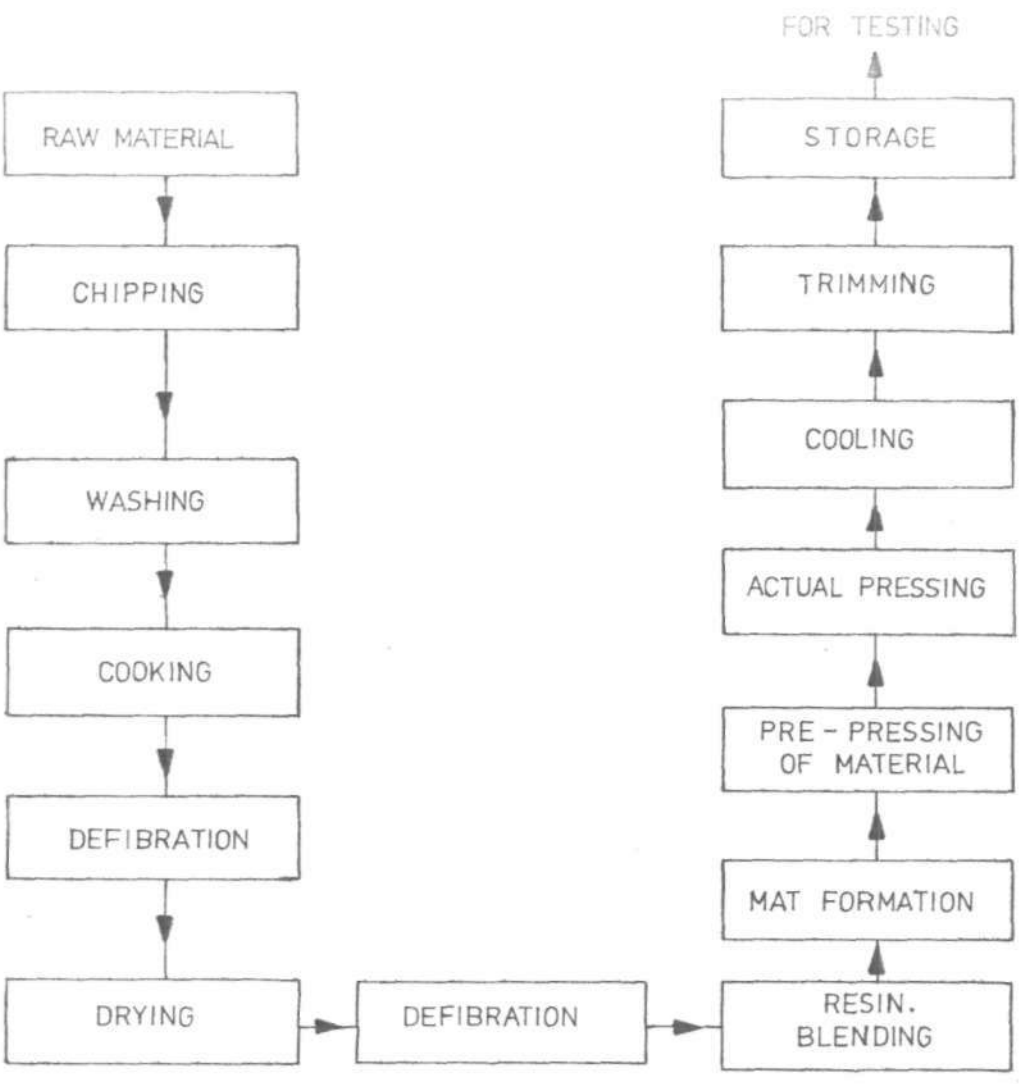


FIG.(2) A SIMPLIFIED FLOW - CHART OF THE LABORATORY PRODUCTION OF MEDIUM DENSITY FIBREBOARD (M.D.F.) FROM COTTON STALKS.

3.10.2. FINAL PRESSING:

After the prepressing, the mat was removed and the temperature of the plates raised to between 130 - 150°C. This heat is necessary for curing resins in the mat. The prepressed mat was at this stage placed in the press and pressed steadily to the required thickness. The forming pressure being a function of the thickness was noted. The pressed mat was left in the press at this temperature for 20 minutes and the temperature was allowed to drop steadily for 10 minutes (i.e. 30 minutes pressing time) after which the board formed was removed from the press for conditioning.

3.11. CONDITIONING:

The board produced was at this stage removed from the press and left in a cool place for one day (24 hours) after which it was trimmed and left in the same cool place for seven days (7 days) before any test was carried out to determine its physical and mechanical properties.

3.12. PROCESS FLOW CHART:

The laboratory samples were produced as discussed earlier and as presented with the simplified flow-chart in Fig. (2).

3.13. THE SPECIMENS:

The data of the produced samples are shown in Table (1).

Table (1) - V Board Production Data

Board No.	Pressure (bar)	Temperature (^{o}C)	Time (min)	Resin Dry (%)	Water (%)	Density (Kg/m^3)
1	24	145	20	10	20	580
2	24	140	20	11	20	600
3	24	145	15	10	16	625
4	24	145	22	11	20	720
5	24	150	20	11.5	20	750
6	36	150	20	11	15	780
7	36	145	25	11	20	860
8	48	150	20	11.5	24	890
9	48	150	25	9	14	900
10	60	155	30	12	18	910

After the production of MDF from cotton stalks was completed, it was necessary to test the samples of these boards for the accurate evaluation of their physical and mechanical properties in use as an engineering material. The tests and test procedure carried out are outlined in the following chapter.

4 - TESTS OF THE MDF SPECIMENS

In order to determine the suitability of the MDF produced from cotton stalks, in use as engineering material, the products had to be tested for the accurate evaluation of their physical and mechanical properties. The tests carried out were basically of the destructive nature. The specimens were tested empirically for their wood working properties.

The tests and test procedures carried out are briefly described below. These tests were carried out in accordance with the procedures specified in BS 1142 Part 1, 1971 and NPA 4-73 (National Particle board Association, U.S.A.) as well as BS 2604 for particle board. The test results are tabulated in Tables (2 to 10) and are shown photographically in Plate 2. Sample calculations for all tests are presented in Appendix (II).

4.1. DETERMINATION OF DENSITY:

The dimensiona of each test specimen were taken at four different points and the average (mean) obtained in each case as the agreed dimension of the specimen. A pair of calipers was used for the measurement. Each test specimen was weighed to an accuracy of 0.1 gm. The volume of the specimen was calculated to

the nearest 100 mm^3 as recommended in the standards.

The density of each specimen was calculated as follows:-

$$\rho = \frac{M}{V}$$

where: ρ = Density in kg/m^3

M = Mass in kg of the test specimen

V = Volume in M^3

4.2. BENDING STRENGTH TEST:

Three specimens of 75 x 180 x t (mm) were tested on rollers of 75 mm x 30 mm diameter. The rollers were kept at 152.4 mm apart and load applied at the centre by the Denison Testing machine. The speed of all tests on this machine was 2 mm/min. The following result was obtained using the formula:

$$S = \frac{3\ PL}{2\ b\ t^2}$$

where:

F = Load at rapture in Newtons (N)

L = Length between supports in millimetres(mm)

b = width (mm)

t = Thickness (mm)

TABLE (2) Bending Strength Test Result

Specimen	Density kg/m^3	Thickness t (mm)	Bending Strength (N/mm^2)	Average N/mm^2
1	860	5.4	20.7	19.6
2	625	10.8	18.4	
3	780	10.3	19.7	

It was noted that the bending strength increases with increase in density. But the density cannot be allowed to go up too much because this will go out of the required limit. This relation is shown in Fig. (3).

4.3. TENSILE STRENGTH TEST PARALLEL TO SURFACE:

Three specimens were tested for the tensile strength test.

The effective dimensions were 38.8 x t (mm) and lengths were 184 mm. The formula used was:

$$T = \frac{P}{A}$$

where:

T = Tensile strength (N/mm^2)

P = Rapture load (N)

A = Cross-sectional area (mm^2)

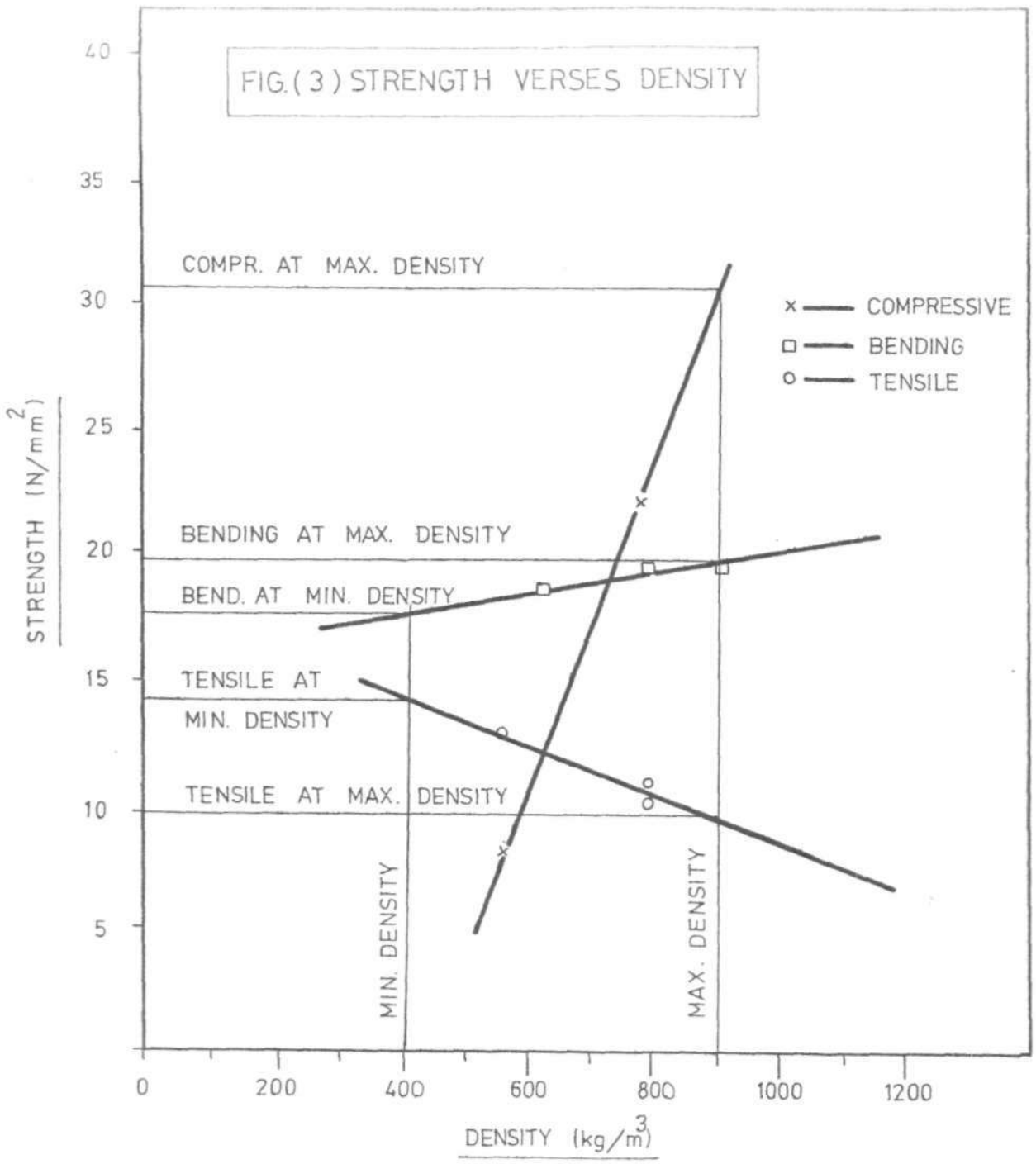
The following results were obtained.

TABLE (3) - Tensile Strength Test Parallel to Surface

Speci-men	Density kg/m^3	Thickness (mm)	Tensile Str. N/mm^2	Mean N/mm^2
1	780	10.3	8.81	9.80
2	780	10.3	8.86	
3	580	7.4	11.83	

It may appear strange that for lower density the tensile strength is higher. But there are two reasons for this:

(a) Higher pressures during forming tend to make boards brittle.


FIG.(3) STRENGTH VERSES DENSITY
STRENGTH (N/mm²)
40
35
30
25
20
15
10
5
COMPR. AT MAX. DENSITY
BENDING AT MAX. DENSITY
BEND. AT MIN. DENSITY
TENSILE AT MIN. DENSITY
TENSILE AT MAX. DENSITY
MIN. DENSITY
MAX. DENSITY
COMPRESSIVE
BENDING
TENSILE
0
200
400
600
800
1000
1200
DENSITY (kg/m³)

(b) Higher temperatures also reduce strength when timing is not increased correspondingly.

A graph of the variation of Tensile strength parallel to board surface is given in Fig. (3).

4.4. TENSILE STRENGTH PERPENDICULAR TO THE SURFACE:

Specimens used here were of sidesd 52.2 x 52.2 mm, glued between two wooden pieces of slightly higher dimensiona.

52 mm wood screws were used as fixture for applying the load using the Denison Testing Machine until the board fractured at about the middle. The Tensile strength perpendicular to the surface was calculated using the same formula as for (4.3). The following results were obtained.

TABLE (4) - Tensile Strength Perpendicular to the Surface

Specimen	Density kg/m^3	Tensile Strength N/mm^2	Average N/mm^2
1	780	0.74	0.70
2	780	0.74	
3	625	0.62	

4.5. COMPRESSION STRENGTH PARALLEL TO SURFACE TEST:

Test was made of specimens with the load applied parallel and perpendicular to the long dimension of the board. The dimensions relatively were:

Thickness - t (mm)

Width - t (mm)

Length - 4 t (mm)

Load was applied using the Denison Testing Machine. The formula for calculation was:

$$C = \frac{P}{A}$$

where:

C = Compression Strength

P = Rapture load

A = Area.

The variation of compressive strength with density is shown in Fig. (3).

TABLE (5) - The Result of the Comp. Str. Parallel To Surface.

Speci-men	Density kg/m^3	Thickness (mm)	Compressive Strength N/mm^2	Average N/mm
1	750	7.2	23.6	23.4
2	750	7.2	23.2	

4.6. NAIL RESISTANCE TEST:

The nail resistance test was done for both parallel and perpendicular direction (with reference to the long dimension). With the Denison Testing Machine, the load required to push the nail through the test specimen, for the push through test or to pull the nail out,

in the case of the lateral nail withdrawal test. The diameter of the nail used was 2.8 mm. The scale reading was the required force directly. The results are given below.

TABLE (6) - NAIL TEST RESULTS

Specimen	Surface Push-through(N)	Lateral Pull-out(N)
1	970	200
2	1000	260
3	1100	300
Average	1024	253

4.7. SCREW WITHDRAWAL TEST:

Screw-holding test was made on screws threaded into the board to measure the resistance to withdrawal in a plane normal to the face. Resistance of screws from the edge of the board was also done.

2.5 mm wood screws were used. The test method was the same as that for nail withdrawal test. The screw heads were cut off for easy fixture. The following results were obtained.

TABLE (7) - SCREW TEST RESULTS

Specimen	Parallel to Surface(N)	Perpendic.To Surface(N)
1	700	1200
2	680	1150
3	650	1150
Average	677	1167

4.8. SURFACE SOUNDNESS:

Soundness of the surface of a MDF board is the force that will tear-off the surface layer. The way to test this was to glue a board piece of 29 x 29 mm between two wood pieces of sides 52 x 52 mm. Load was applied just as in the case of perpendicular tensile test.

Here, fracture took place at the surface of the board unlike the tension case where fracture was at the centre. The results obtained are given below.

TABLE (8) Surface Soundness Test Results

Specimen	Surface Soundness (N)	Average (N)
1	2000	2200
2	2400	

4.9. WATER ABSORPTION AND THICKNESS SWELL TEST:

All board produced had no water repellents added. The test specimens were square (60 x 60 mm). Three specimens were used. The steps in this test were:

(a) Measurements of weight, thickness,width and length were done by means of a balance and vernier caliper.

(b) Specimens were placed in water to soak. They were made to be completely covered in the water.

(c) After two hours the specimens were removed and the excess water allowed to drip off.

(d) The weight and dimensions of the board were then taken.

(e) The boards were returned into the water basin and left for 22 more hours.

(f) They were then removed again, and the excess water allowed to drip off. The weights and dimensions were then taken again.

The results for water absorption and thickness swell are given in Table (9).

TABLE (9) - Water Absorption & Thickness Swell Test Results

	2 Hours			24 Hours		
Specimen	Water Absorption %	Thickness Swell %	Length increase %	Water Absorption %	Thickness Swell %	Length increase %
1	88.7	57	0	105.0	72	0.3
2	54.8	28	0.4	68.6	31.4	0.5
3	45.2	36.5	0.4	78.4	52	0.6
Average	62.9	40.5	0.27	84	51.8	0.47

4.10. MOISTURE CONTENT TEST:

The moisture content of boards was measured by weighing the board on a beam balance, drying in furnace for a period of 24 hours at 102 - 108^{o}C and then cooling in a desicator and weighing for the second time.

Three specimens were used, and the results calculated from the formula:

$$Mn = \frac{M_1 - M_o}{M_o} \times 100\%$$

where:

M_o = Oven dry mass in gm.

M_i = Initial mass in gm.

The test results are tabulated in Table (10).

TABLE (10) - Moisture Content Test Results

Specimen	Density kg/m^3	Moisture Content (%)	Average Value (%)
1	790	3.94	
2	790	3.83	3.53
3	625	2.82	

In view of the results got from these tests, discussions are to be made and conclusions to be drawn. This is done in the next chapter.

5 - DISCUSSION OF TEST RESULTS

The discussion to be made in this chapter is mainly based on the values of the tests carried out on samples of the medium density fibreboard, produced from cotton stalks, as earlier stated. The results are hereby compared with the standard values as found in BS 1142, Fibre-building boards and BS 2604, for particle boards. So far, no international standard has evolved for the medium density fibreboard. Hence the results obtained from the tests are to be compared with the standard limits set for the particle board as found in BS 2604, Part 2, 1970. This comparison is necessary since both the MDF and the particle board (within the same density range) are used almost to serve the same purposes, for example, in furniture and building construction, etc. Also, since there is no international standard for the MDF and it is required that the suitability of cotton stalks for the manufacture of MDF be investigated, it is more reasonable to compare the results got with those standards established for the particle board which has very similar characteristics with fibreboards.

A summary of the test results based on average values is given in Table (11). Standard values are also given in the same table for comparison. The standard used is the

British Standard BS 1142 (Fibre Building Boards) and BS 2604 (Particle Board). No standards exist for MDF specifically.

TABLE (11) - Test Results For MDF From Cotton Stalks

No.	Specification	Units	Average Test Value	Standards	
				BS 1142 Fibre-Board	BS 2604 Particle Board
1	Density	kg/m^3	760	400-800	480-800
2	Bending Strength	N/mm^2	19.6	8-15	13.8
3	Parallel Tensile Strength	N/mm^2	9.8	-	-
4	Perpendicular Tensile Strength	N/mm^2	0.7	-	0.38
5	Compressive Strength	N/mm^2	23.4	-	-
6	Nail Push Through	N	1024	-	-
7	Nail Head Pullout	N	253	-	-
8	Perpendicular Screw Withdrawal	N	1167	-	360
9	Parallel Screw Withdrawal	N	677	-	-
10	Surface Soundness	N	2200	-	1100
11	Water Absorption After - 2 hours -24 hours	 % %	 62.9 84.0	 - 40	 - -
12	Thickness Swell - 2 hours -24 hours	 % %	 40.5 51.8	 - 20	 - 12
13	Lengthwise Swell - 2 hours - 24 hours	 % %	 0.27 0.47	 - -	 - -
14	Moisture Content of Board	%	3.53	-	-

5.1. DENSITY:

The density range of the products lay perfectly within the ranges recommended in BS 1142. A greater number of the specimens produced lay in the upper range, that is 600 - 800 kg/m^3.

This large density variation indicates that cotton stalks, like other raw materials for the manufacture of MDF can produce boards whose density variation is independent on the density of the raw material, but rather, on strength requirements, economy of raw materials and capacity of equipment.

Increasing the density of the board and keeping other parameters the same lead to the following effect:

(a) Reduction of tensile strength.

(b) Increase in nail push through force without necessarily increasing the screw holding properties.

(c) Compressive strength increases to a certain maximum and then drops again.

(d) Increase in bending strength.

In general, high density tends to give rise to hardboards which are not required and cannot be used in many areas where MDF are recommended. Furthermore, since the required properties are best for boards within the MDF range, no need to waste materials.

The strength of the lower density boards could be increased by increasing the resin composition by one or two percent. But since the resin is the most expensive aspect of the manufacture of MDF, this needs not be done.

It ought to be noted also that a high initial moisture content during production leads to higher density boards. This feature is due to the fact that fibres are more compressible when wet. Care must be taken therefore in controlling the moisture content when producing light boards; If the moisture content is not enough, board may develop low internal bond. This gives rise to bad boards which are better called soft boards and no more MDF.

5.2. BENDING STRENGTH:

The bending strength which is 19.6 N/mm^2 is 30% higher than the maximum,indicated in BS 1142 and 40% higher than that for particle boards. This achievement not only shows the quality of boards made from cotton stalks, but also the superiority of MDF to other types of boards.

Increase in density gives a rapid increase in bending strength. The fibrous nature of cotton stalks play a vital role in the high bending strength. The ribres interlock as indicated in the structure of the fracture lines of test specimens.

Bending strength can be increased by increasing resin content. But higher forming temperatures tend to reduce the strength of board in the higher density range.

5.3. TENSILE STRENGTH:

There is no standard for tensile strength parallel to surface so nothing can be said about this. But for the perpendicular tensile strength, which is 0.70. it is 84% higher than the value for particle board as given in BS 2604.

Tensile strength properties are necessary for boards which are to be used for connections between two furniture components. This is well achieved in these products.

Parallel tensile strength tends to decrease with increase in density. But this decrease is very low as is noted from the slope of the graph in Fig.(3).

5.4. COMPRESSIVE STRENGTH:

The graph of compressive strength versus density shows a maximum at about 750. kg/m^3. This characteristic is due to:

(a) Softness of the board at low density.

(b) Brittleness at densities in the hard board range.

The mean maximum compressive strength is 23.4 N/mm^2.

5.5. NAIL PUSH-THROUGH AND SCREW WITHDRAWAL:

These tests give satisfactory results. The screw withdrawal perpendicular to the surface, which is 1167 N is over 200% better than that for particle board (BS 2604). Tests were conducted on specimens of about 10 mm thickness.

The screw withdrawal parallel to the surface is low. The main reason is the variation of test specimens. But also the layer-structure that tends to develop in boards in the high density range contribute.

The nail tests show similar variations as the screw tests. But no standards exist, with which to compare. It was noted that it was harder to initiate a nail hole than to pull it out through its hole.

Nail and screw tests show how MDF products are usable for most furniture works.

5.6. THICKNESS SWELL:

Thickness swell is a measure of the increase in the thickness of the board when it is immersed in water.

While the chickness of the board increased by an amount up to 52% (24 hours immersion) the length and width increased by only 0.5%.

Two reasons can be given for this observation.

(a) During forming there was no lateral flow, hence no residual stresses are present in these directions.

(b) Heating of the formed mat starts at the surface of the hot plates and then move inward. This means that the curing of the resin also starts at the hot plate surface. Hence steam and other gases and are trying to escape, tend to move outward between subsequent layers. So added to the residual stresses in the thickness direction, dislocations are created.

So when the board remains in water for some time, these stresses are released as the water enters through the dislocation line.

Water repellents like wax, if added would have closed these 'water ways' and not only reduce the thickness swell but also the water absorption property.

5.7 - WATER ABSORPTION:-

The water absorption of MDF produced from cotton stalks was very high. Not only that, it was also very quick.

The 24 hours water absorption by weight was 84% while that for two hours was 63%; a difference of only 21%.

These results do not mean that cotton stalks have bad water absorption properties.. What they show is the importance of water repellents. For apart from the fact that no wax was added the surfaces were not resin treated.

An addition of wax of even less than one percent will surely reduce the water absorption drastically. Water repellents do not improve the strength properties of the boards. It was noted that the boards dry to normal strength after soaking.

5.8. MOISTURE CONTENT:

The final moisture content of the products gave an average of 3.53%; this value is as low as the initial moisture content of the chips. This indicates the fact that unlike in the production of particle boards where final moisture content depends on the initial value, moisture content of the products depends only on the pressing conditions and the type of conditioning of the board after the pressing process.

There is therefore no fear of warping or dimensional changes due to minor variation in the humidity of the atmosphere.

6 - CONCLUSION OF THE DISCUSSION OF RESULTS

From the foregoing discussions, the following conclusion can be drawn:

(a) The following tests had no definite standards to compare with:

(i) Parallel tensile strength.

(ii) Compressive strength.

(iii) Nail push/pull through tests.

(iv) Length variation.

(v) Thickness swell (2 hours).

(vi) Moisture content.

So these values are given pending the time when relevant standards will be established.

(b) Bending strength and tensile strength values are in acceptable range.

(c) Wax is a necessary additive to avert water absorption and thickness swell.

(d) Production control has had great effect on:

(i) Final moisture content.

(ii) Thickness swell and water absorption.

(iii) Surface properties.

This means improper production control easily creates defects in the above mentioned areas more pronounced than in other areas.

Finally, on the basis of the test results and the foregoing discussion, it is clear that cotton stalks are highly recommended for the manufacture of Medium Density Fibreboard.

7 - RECOMMENDATIONS

It is proved from the test results that the cotton stalks are good materials for the making of medium density fibreboard. Therefore, it is strongly recommended that an industry based on this technological tests be established and investigation be carried out to substantiate the economical viability of such industry in Northern Nigeria.

This should be started by carrying out detailed Feasibility Study, showing the technical and economical aspects of the project.

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STANDARDS:

BS 1142: Part I, 1971 Specification for Fibre Building Boards. Part I Method of Tests.

BS 1142: Part II, 1971, Medium Density Fibreboard and Hardboard.

BS 1142: Part III, 1972, Insulating Board (soft board).

BS 2604: Part II, Specification for Resin-Bonded Chipboard.

USA(NPA): Standards for Medium Density Fibreboard by National Particle Association, U.S.A.

9 - NOMENCLATURE

1.	Um	-	micro-metres
2.	mm	-	millimetre
3.	m	-	metre
4.	kg	-	kilogrammes
5.	N	-	Newtons
6.	KN	-	Kilo Newtons
7.	M_o	-	oven-dry mass
8.	M_1	-	initial mass
9.	M_2	-	mass after soaking in water
10.	M_c	-	moisture content
11.	A	-	water absorption
12.	L_1	-	initial thickness (length)
13.	L_2	-	final thickness(length)after soaking in water
14.	G	-	thickness swell
15.	S	-	bending strength
16.	Ts	-	tensile strength
17.	Cs	-	compressive strength
18.	P	-	load
19.	L	-	length
20.	b	-	width
21.	a	-	thickness
22.	A	-	area.

DEFINITION OF TERMS USED IN THE REPORT

Additive: Any special material incorporated in a panel in the course of manufacture to impart special properties. The term includes preservatives and water repellents and fire retardants but not binders.

Adhesive: A substance capable of holding materials together by surface attachment. The term is used to cover the bonding of sheet material and is synonymous with glue.

Binder: Organic bonding agent used to bind together the fibres in a fibreboard.

Curing: The physical-chemical change brought about in thermo-setting synthetic resins under the influence of heat and a catalyst (Polymerization).

Flat-Platen Pressed Board: Board pressed in a parallel platen hot press, usually of the multi-platen type. May be pressed in a continuous press. The applied pressure is perpendicular to the plane of the sheet.

Formation (Forming): The laying of the blended mass of fibres to form a mat for fibreboard.

Hardener: A chemical agent used to promote the setting of a synonthetic resin adhesive. The term is synonymous with catalyst.

High Frequency Heating(H.F.): Dielectric heating by high frequency electrical energy.

Hot Pressing (H.P.): A process of pressing between hot platens of a press to form a panel (fibreboard).

Resin Blanding: The application of the binder to the fibres (i.e. mixing them together).

Resin Content: The amount of dry solids in the resin, related to the dry weight of the finished boards.

Synthetic Resin(Thermo-Setting): Artificial resins (as opposed to natural used in board manufacture as a binder. If polymerized, e.g. by the application of heat into compound which is used to produce the bond in fibreboard. Types usually used in board manufacture are phenol-formaldehyde, Urea-formaldehyde, or Melamine-formaldehyde.

10 - A P P E N D I X I

INDUSTRIAL PRODUCTION OF MEDIUM DENSITY FIBREBOARD:

In the following, the different industrial production steps of dry process MDF are considered.

CHIP PRODUCTION, PREPRESSING OF RAW MATERIAL

The process of manufacture begins with the production of chips or the use of different kinds of wood wastes. For wet particles the chips and wood waste respectively are dried by means of a pre-drier to a residual moisture of 25% (oven dry basis). The pre-drying shows the following advantages:

(1) Dust and sand particles are removed and therefore can be sifted out easily and this has a positive effect on the service life of the refiner grinding discs.

(2) Because of the insignificant intial moisture of the chips, after boiling and defibration the fibres have a final moisture of only approximately 35%. This permits low temperatures for the fibre drying consequently leads to reduced fibre risks. Additionally, owing to the low temperature prior to main drying Urea resin may be applied by the blow-pipe process. By this kind of gluing, glue spots on the manufactured panels are avoided.

BOILING, DEFIBRATION AND DRYING:

Subsequently the pre-dried chips are screened so that dust and fines can be conveyed to a combustion plant. From an intermediate silo the screened chips having passed a sifter for heavy materials are transported further into a boiler heated by saturated steam. Depending on the wood species and the form, chips are softened during an interval of 3 - 6 minutes and temperatures of 160 - 180°C and at pressures of 6 - 10 bar. The chips are finally defibred by means of a two-discs-refiner - the one disc rotating and adjustable, the other one fixed.

The defibred wood material with a moisture content of approximately 35% is then blow-piped into a steam cyclone, from where it falls into a tubular drier.

GLUING AND DRYING:

By means of one or two simple nozzles, 8 - 10% Urea or Phenolic Resin is proportionately applied to the fibres in a blow pipe bringing the fibres up to a maximum moisture content of 45%. Water repellents may either be added to the resin or introduced into the refiner as pure liquid wax. The low initial fibre moisture content of approximately 45% when entering into the pipe drier permits a relatively low drying temperature.Because the glue is applied prior to entry into the drier, the fibre

material must only be dried down to a relatively high moisture content of 14%. This is controlled by a continuously working measuring device. In some plants the steamed wood particles are fibrized in a steam pressurized refiner, dried to 5 - 15% moisture content and treated with 7.5 - 9.5 resin solids (oven dry fibre basis).

MAT FORMATION AND PRESSING

After adding the resin the next step is the formation of the material into mats that later will be pressed. Fibres are continuously formed into mats by various systems. In one system, the fibre transport is made pneumatically and the mat is formed by one or more forming heads, which distribute the fibres by means of air streams on an endless wire that runs through the forming station. The forming air is drawn through the forming wire and the vacuum boxes underneath and the fibres form a continuous mat on the wire. The pneumatic forming gives a very good control of the density spread and gives, in other words, a very even mat.

A high pre-compression by means of a continuously working pre-press of the fibre mat is achieved. Subsequent Radio-Frequency (RF) pre-heating up to 70 - 80°C in a continuous process permits pressing times of 5 sec/mm per gross panel thickness in a single opening

press with combined contact and R-F heating devices. The pre-pressed mats are cut-to-length, and pressed to thickness between steam heated platens. In the "Hot press" (H.P) process, all the heat for curing resins in the mat is obtained from the hot platens. In the "RF process" heat from the hot platens is augmented by heat from high frequency electric power.

After pressing boards are conditioned for about 24 hours, trimmed and sanded on both sides before being packed and shipped to the end users.

11 - APPENDIX II SAMPLE CALCULATIONS

1. Bending strength

$$S = 3\,PL/2ba^2 \ (Nmm^2)$$

$P = 0.20$ KN

$L = 152.4$ mm

$b = 75.7$ mm

$a = 5.4$ mm

$$S = \frac{3 \times 200 \times 182}{2 \times 75.7 \times (5.4)^2} \quad N/mm^2$$

$$= 20.7 \ N/mm^2$$

2. Tensile Strength

$$Ts = \frac{P\ max}{A} \ (N/mm^2)$$

$P\ max = 3.5$ KN

$A = 7.4 \times 39.8 \ mm^2$

$$Ts = \frac{3500}{7.4 \times 39.8} \ mm^2$$

$$= 11.88 \ N/mm^2$$

3. Compressive Strength

$$Cs = \frac{P\ max}{A} \ (N/mm^2)$$

$P\ max = 4.9$ Kn

$A = 13.6 \times 16.5 \ (mm^2)$

$$Cs = \frac{4900}{13.6 \times 16.5} \ (N/mm^2)$$

$$= 21.8 \ (N/mm^2)$$

4. Water Absorption

$$A = \frac{M_2 - M_1}{M_1}$$

$M_2 = 72.0$ g

$M_1 = 49.6$ g

$$A = \frac{(72.0 - 49.6)}{49.6} \times 100\%$$

$$= 45.16\%$$

5. Thickness Swell

$$G = \frac{L_2 - L_1}{L_1} \times 100\%$$

$L_1 = 13.8$ (mm)

$L_2 = 18.7$ (mm)

$$G = \frac{18.7 - 13.8}{13.8} \times 100\%$$

$$= 36.49\%$$

6. Moisture Content

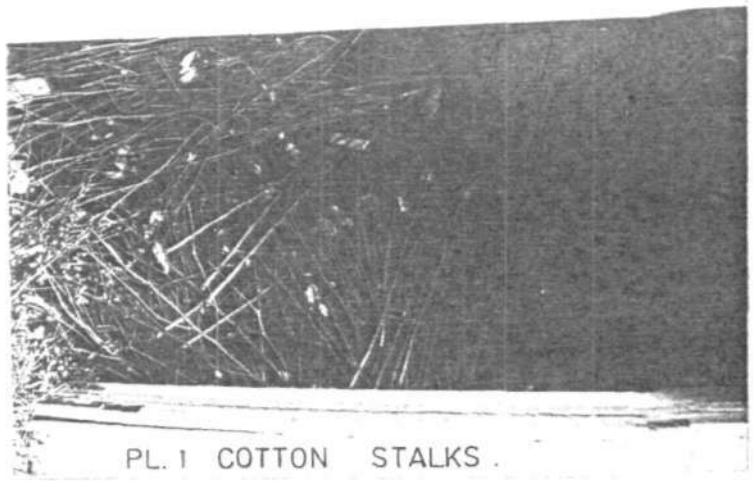
$$\text{Moisture content} = \frac{M_1 - M_o}{M_o} \times 100\%$$

$M_o = 55.8$ g

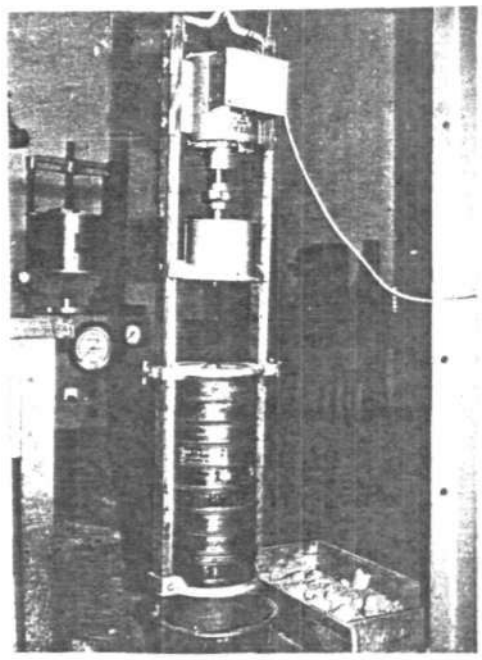
$M_1 = 58.0$ g

$$M_c = \frac{50.0 - 55.8}{55.8} \times 100\%$$

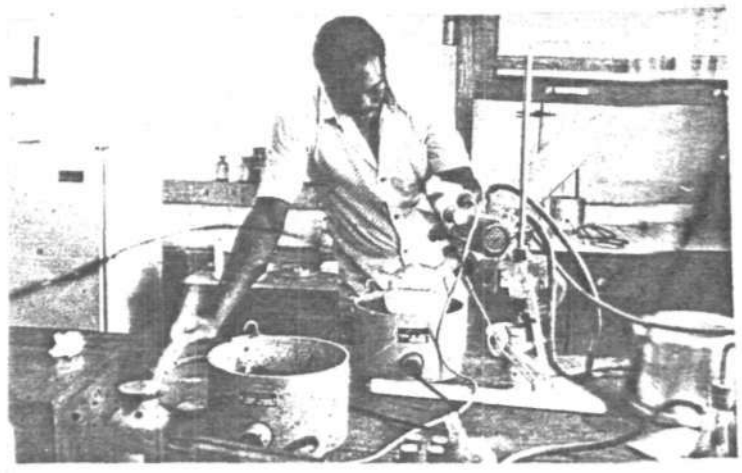
$$= 3.94\%$$



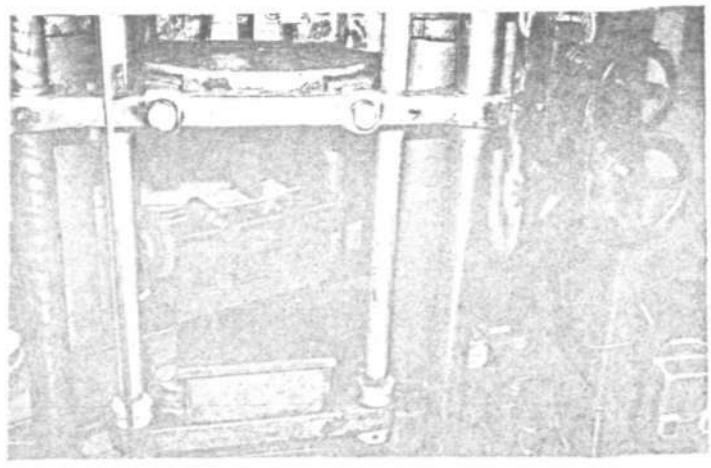
PL. 1 COTTON STALKS.



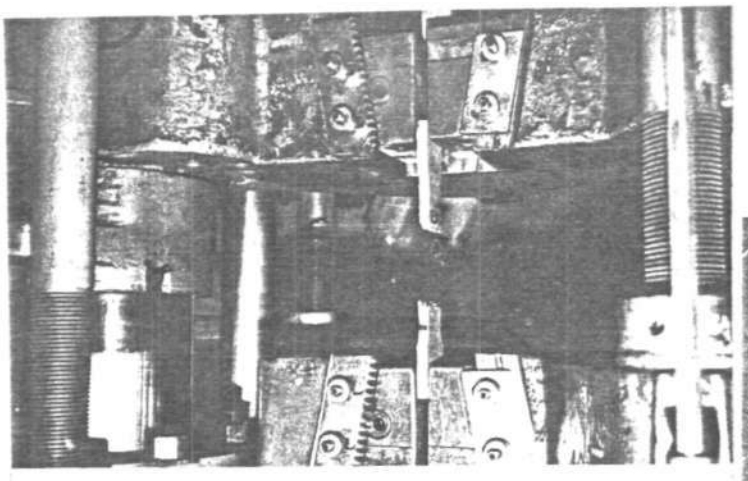
PL 2 GRADING THE CHIPS.



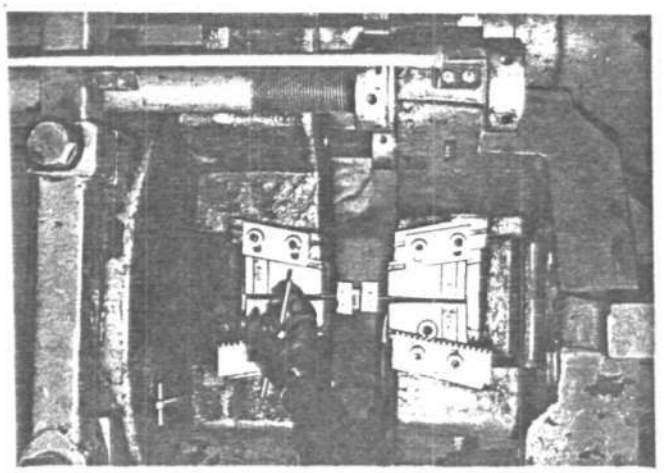
PL 3 PREPARING THE CHEMICALS.



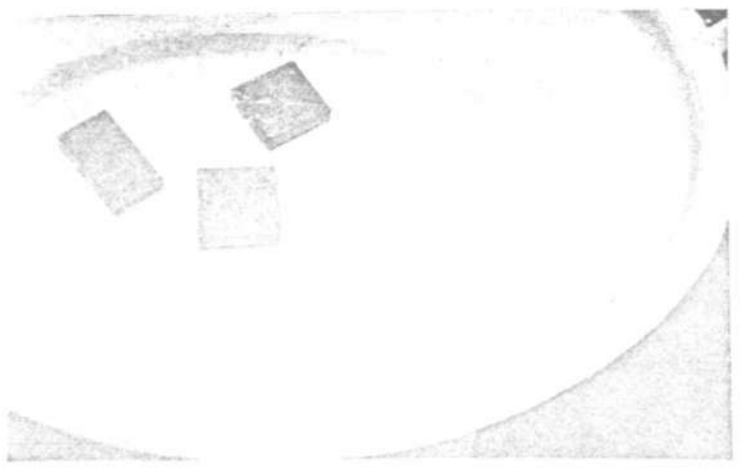
PL 4 BENDING TEST.



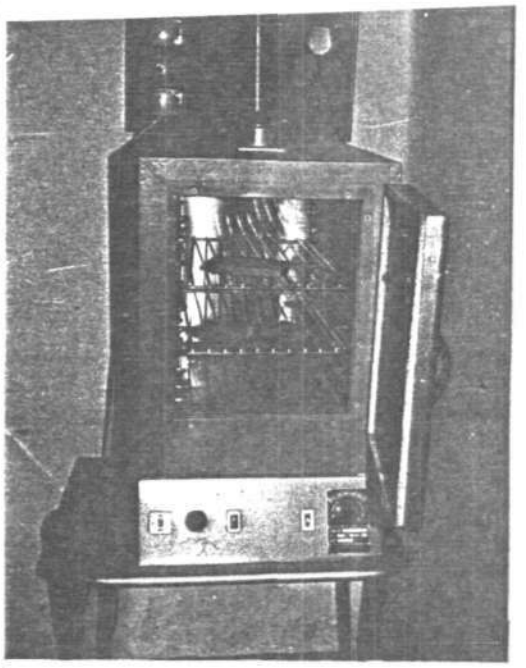
PL 5 TENSILE TEST.



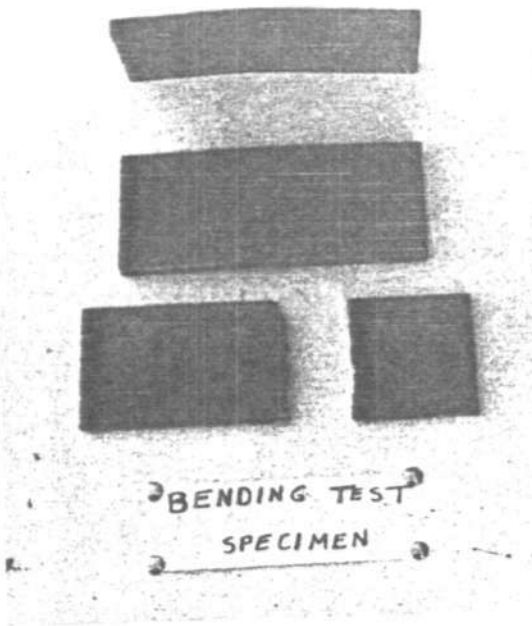
PL 6 SURFACE SOUNDNESS TEST.



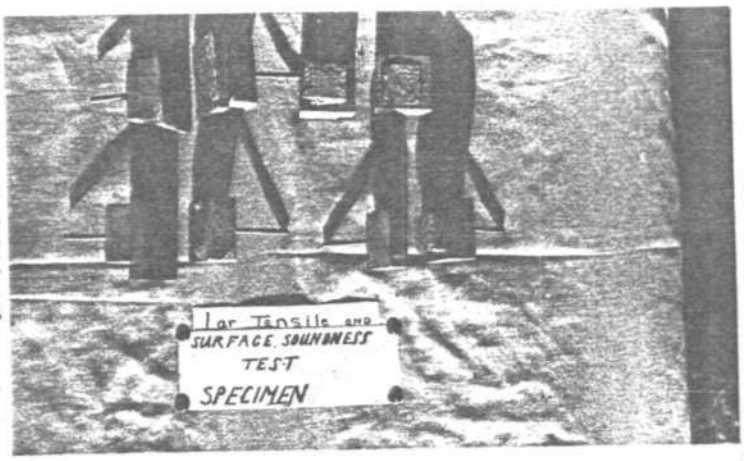
PL 7 WATER ABSORTION AND SWELL TEST.



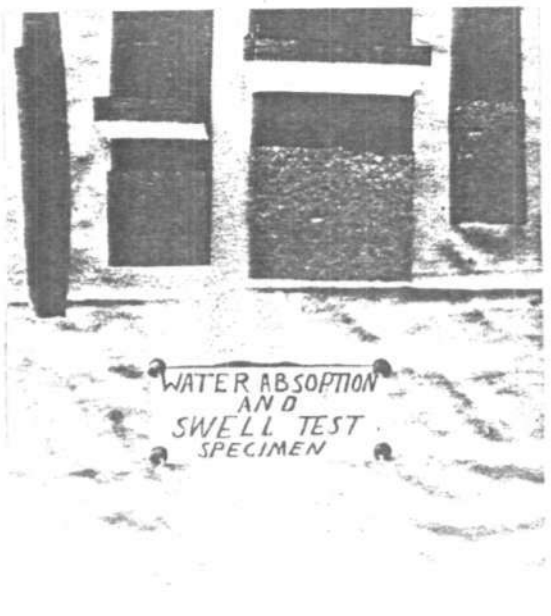
PL8 DRYING THE SPECIMENS .



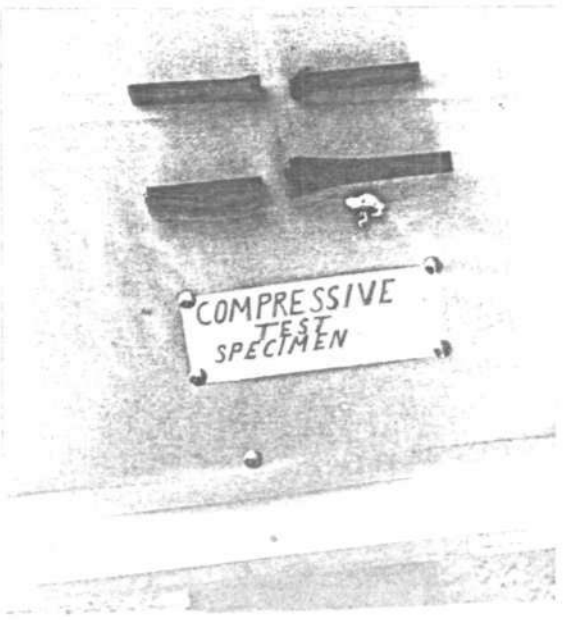
PL 9



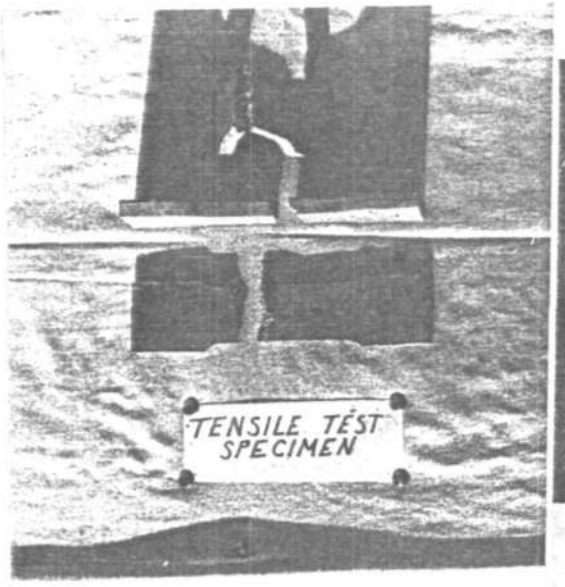
PL 10



PL 12



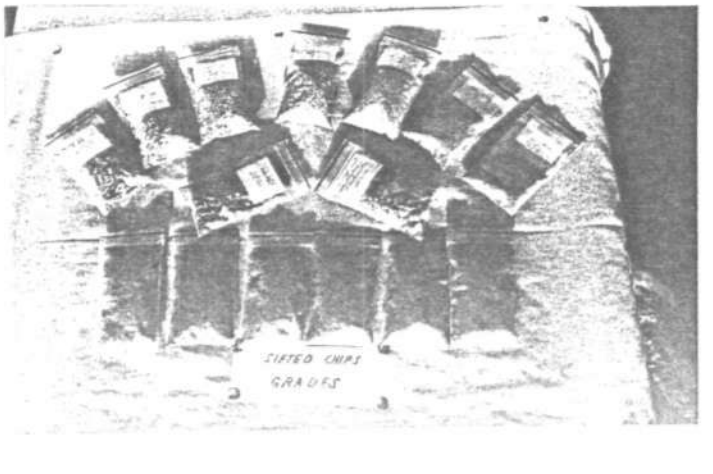
PL 11



PL 13



PL 14



PL 15