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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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DEVELOPMENT OF JUTE BASED PACKAGING MATERIALS

A. Biswas*, A.J. Hammond,
N.L. Hancox and A. Rana*

Advanced Engineering Materials Department,
AEA Technology,
Harwell Laboratory,
Didcot,
Oxfordshire. OX11 0RA

*Indian Jute Industries Research Association.

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DEVELOPMENT OF JUTE BASED PACKAGING MATERIALS

A. Biswas*, A.J. Hammond,
N.L. Hancox and A. Rana*

ABSTRACT

A simple rig was designed and built to:

(1) Impregnate jute cloth with powdered polyethylene.

(2) Corrugate the sheet produced.

(3) Heat weld two plain, flat, sheets of impregnated jute cloth to the corrugated core to make a sandwich material.

It was possible to get good impregnation up to a throughput speed of about 1100 mm min^{-1}.

The properties of impregnated sheet and sandwich structure were determined. Impregnating one side of the cloth increased the tensile strength by 44% and impregnating both sides by 54%. The sandwich material had a mass per unit area of 1.92 Kg m^{-2}. Its burst strength, edge and crush strengths and puncture resistance were comparable with those of a high quality corrugated core paper material.

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1. INTRODUCTION

In a previous report, AERE-G5225, the rationale for using jute composites for packaging and development work on producing these materials was described. Composites were manufactured using urea, melamine and phenol formaldehyde resins and polypropylene and polyethylene as matrices. The composites were mainly in the form of thin laminates though some corrugated sheets were produced.

The corrugated material is an excellent core for a stiff sandwich structure and this system, of face skins and a corrugated centre, was chosen for development as a packaging material. Previous mechanical tests had shown that thermoplastic matrix jute reinforced composites were as good as thermoset materials and since the former could be heat welded it was decided to use a thermoplastic matrix in the development work on sandwich structures described here.

The present programme consisted of developing a rig to make good quality, flat, laminates, adapting it to produce corrugated material and finally using the rig to combine the core and face sheets into a sandwich structure. A limited amount of evaluation work was carried out on the material.

2. MATERIALS

A balanced weave jute fabric, with salvaged edges, 240 mm wide and containing 6 picks per cm in both warp and weft directions was used throughout the work. The areal density was 294 gm^{-2} and the thickness 0.8 to 0.9 mm. The oil content was believed to be of the order of 1%. The cloth was neither cleaned nor steam consolidated prior to use.

Although some work was carried out with lay-flat polyethylene sheet (standard Harwell stores issue, 0.05 mm thick), for the majority of the project Hostalen GR 7255P, powdered, high density polyethylene, supplied by Hoechst Ltd., was employed. Some properties of this are listed in Table 1. In addition a little work was carried out using water based emulsions of polyvinyl chloride, numbers 576 and 351, supplied by B.F. Goodrich Ltd.

3. EXPERIMENTAL WORK - FABRICATION

3.1 Possible Processing Methods

There were four possible processing methods available to produce jute composite, viz:

- Sequential moulding - a batch type process ideal for the pressure moulding of flat sheet. Tooling might be expensive if this route was used to produce corrugated sheet.

- Pultrusion - a continuous, commercial, process. Again tooling could prove expensive.

- Extrusion - the output rate would be high and the process could handle short fibres. Tooling could be expensive.

- Rolling - rollers would be cheaper to make than dies. A combination of plain and corrugated rollers could reduce three ply board manufacture to a single operation. Manufacturers of paper packaging products use this method and the output rate is high.

3.2 Initial Development

It is helpful to consider the evolution of the final rig and hence details of some of the preliminary methods of impregnating jute cloth with a polymer are described below.

After careful consideration, including an assessment of the equipment available at Harwell and that likely to be readily available in India, the roller route was chosen. The first attempt at continuous impregnation utilised a pair of hand driven steel rollers to pull the jute cloth, faced on one or both sides with lay-flat polythene sheet and PTFE coated glass cloth release film, between press platens 1 mm apart heated to 150°C. The feedstock was 1.15 mm in thickness and the gap between the rollers 0.5 mm. The final composite sheet had a thickness of 0.77 mm. External coating was excellent and penetration of the polyethylene into the jute occurred.

Further trials used a heated double roller mill but the maximum temperature achievable, 130°C, proved to be insufficient, feedstock slippage occurred and fibre damage was noted.

An improved rig was constructed consisting of two vertical plates which housed interchangeable duralumin rollers 132 mm in diameter x 310 mm long. The position of the upper roller could be adjusted to accommodate varying thicknesses of material. The lower roller was driven by a $^1/_3$ HP motor through a variable speed gear box. The rollers served to consolidate the composite and draw the material through the rig. Initially the jute and polyethylene film were heated by infra-red lamps. However, it was not possible to obtain good penetration of the jute by the polymer. Increasing the amount of polyethylene sheet used made matters worse as the polymer films adhered to one another and left the jute virtually untouched. Increasing the temperature above 150°C caused the polymer to blister. Consequently the heater lamps were replaced by platens 450 x 300 mm each containing 3 1 kW elements. The position of the lower platen was adjustable. Using this rig with a platen gap of 1.2 mm, a roller gap of 0.5 mm and a feed rate of 600 mm min^{-1}, a jute composite containing 38.2 $^w/o$ of polymer was produced. Although the degree of penetration of the cloth was reasonable it was decided that to improve this, and hence obtain a stiffer composite, powdered polyethylene should be used.

3.3 <u>The Powder Route</u>

To impregnate one side of the jute cloth a feedstock consisting of cloth covered with release film was used. Powdered polymer was poured onto the top of the jute, and underneath the release cloth, and spread out with a blade placed at right angles to the direction of travel of the cloth. The sandwich of jute, powder and release film was pulled through the heated platens using two rollers. The platen temperature ranged from 160-220°C though the value was approximately constant during any particular run. Problems occurring were white areas on the jute due to poor polymer melting, distortion of the jute due to uneven tension and a tendency for the rig to jam due to failure of the release film and a build up of polymer in the system.

Better performance was obtained by having the spreader blade profiled on both edges, giving a contact width of 1 mm, and spring loaded so that it could follow changes in the feedstock thickness automatically. It was noted that a blade clearance greater than 1.3 mm gave a clear finish indicative of good polymer penetration. Powder distribution was adjusted so that it was never closer to the edge of the jute cloth than 12 mm. To make powder loading easier a continuous belt of release film was used to encircle the upper heating platen and roller. Unfortunately the problem of joining the belt in such a way as to survive the processing temperature and not damage the composite was not solved satisfactorily and eventually this approach was abandoned. Instead a roll of non-porous peel ply 0.25 mm thick, separating the polymer from the hot surfaces, was fed through the rig, recovered and reused. While a heavier grade of release material improved the finish of the composite and degree of penetration of the polymer, reducing the throughput speed and passing a coated cloth through again did not.

The overall control of the process was improved by running both platen heaters off the same unit, adding three rollers to guide and pretension the incoming jute cloth and maintaining all the components on a rigid base.

To summarise: the parameters for the efficient running of the rig to produce flat jute laminates were:

- Blade gap 1.3 mm.
- Heater gap 2.0 mm.
- Roller gap 0.5 mm.
- Platen temperature 200°C.

- Feedstock speed 600 mm min^{-1}.

- Non-porous peel ply PTFE glass release cloth 0.25 mm thick.

A typical sequence of operations was as follows:

- Stabilise heater temperature with platens open.

- Feed the jute cloth through the pretensioning and guide rollers and up to the compression rollers.

- Insert the release cloth into the system, above the jute cloth.

- Run the compression rollers until the feedstock was gripped.

- Close the heating platens and lower the powder distribution blade to their preset gaps.

- Locate the polymer powder guides adjacent to the blade and add the powder to the jute cloth.

- Start the compression rollers.

- Separate the impregnated jute cloth from the release paper.

This method can be used to impregnate one or both sides of the cloth, though the latter must be carried out in two passes.

The thickness of the processed material is 0.7 to 0.9 mm and the weight loading of polymer, 22.7-27.2 $^{w}/o$, based on the overall sample size.

A schematic diagram of the side of the rig is shown in Figure 1.

Figure 2 shows the rear of the rig with a continuous roll of release cloth in place. Note the three pretensioning/guide rollers and the spring loaded scraper blade. Figure 3 shows the powdered polyethylene being poured on the cloth and the manner in which it is distributed by the scraper blade, while Figure 4 shows the complete rig processing jute cloth. The degree of cover/impregnation of the jute on exiting the rig is clear in Figure 5 and at a greater magnification (approximately x6) in Figure 6.

3.3 The Production of Corrugated Sheet

To produce corrugated sheet the two plain rollers used for gripping and compaction were replaced by two corrugated rollers, see Figure 7. Each had 33, 6 mm high teeth evenly spaced (12 mm pitch) around a pitch circle with a diameter of 126.1 mm. The clearances between meshed teeth was equal to the cloth thickness and was achieved by opening each flute to 6.35 mm.

In the initial runs the corrugation gap was 0.5 mm, the heater gap 3.5 mm, the heater temperature 120°C and the speed of throughput 300 mm min^{-1}. The release cloth and scraper blade were omitted. Cloth coated on one side with polymer did not totally follow the corrugators and there was some damage visible on the profile wall. The final pitch length was 14.7 mm and the height 5.4 mm. A better profile was obtained by increasing the temperature to 160°C, but the best results were obtained with cloth coated on both sides and a platen temperature of 200°C. The pitch in this case was 14.9 mm and the height 5.5 mm. The corrugating rollers are visible in Figure 8 in which impregnated jute cloth feedstock is being fed through the equipment. The corrugated material produced is illustrated in Figure 9 and in greater detail in Figure 10 (x3 approximately).

3.4 Board Manufacture

The final stage in the process was to produce a board or sandwich structure consisting of, basically, two face sheets bonded to a corrugated core.

The initial attempt, involved corrugating a sheet in the usual way and bonding it, on exiting, to a plain, coated, jute sheet. The interface was heated with an infra-red lamp and the two components pressed together. Unfortunately the two sheets did not adhere well and this approach was not pursued.

The second method involved using three sheets, two plain and one corrugated, but each coated on one side with polyethylene. Thus one joint would be polymer to polymer and one polymer to jute cloth. The face sheets were laid on either side of the core and all three fed through the platens, with a gap of 6 mm and heated to 200°C, together. Although there was a good polymer to polymer bond there was very poor polymer to jute bonding with little polyethylene flow into the jute cloth.

It was decided to coat all jute cloth used on both sides and use this material for preparing sandwich boards. The feedstock, prepared by passing the jute cloth through the rig twice, had an approximate polymer loading of 45 $^{w}/o$ and a thickness of 0.8 to 1 mm. Using this material face skins were successfully bonded to the core to give a board 6 to 6.2 mm in thickness with a corrugation pitch of 14.5 mm, a bulk density of 0.32×10^3 Kg m^{-3} and a mass per unit area of 1.92 Kg m^{-2}. The rate of throughput was 300 mm min^{-1}, the platen temperature was 200°C and no release cloth was required. Examples of jute corrugation with one and two layers of plain, impregnated, jute sheet respectively are shown in Figures 11 and 12 (x3 approximately).

Some slippage occurred at the front rollers and to improve the running of the rig another pair of vertical rollers, in line with the existing pair, were added. The lower roller of this pair was coated with 60 grade emery cloth and driven in common with the existing lower roller on the rig. The upper of the second pair of rollers was a free floating, weighted, unit which pressed the completed board onto the emery covered surface to give an improved grip. Typical settings were; heated platen gap 7 mm, roller gap 6 mm. Using this set up 9 lengths of sandwich board were prepared for further evaluation.

3.5 Five Ply Board Specimens

To improve the stiffness of the finished board and its isotropy five layer specimens, including two corrugated cores, were produced.

All internal layers were double coated to improve adhesion. Some assistance was required to pull the charge through because of back tension but good quality board, with only the occasional partially collapsed corrugation, was produced. An edge section of this material is shown in Figure 13 (x4 approximately). The rig parameters were heater temperature and platen gap 200°C and 12 mm respectively, roller gap 10 mm and throughput rate 300 mm min^{-1}. The resulting board had a thickness of 8.1-10.8 mm, as bulk density of 0.38 x 10^3 Kg m^{-3} and a mass per unit area of 3.65 Kg m^{-2}.

To improve isotropy the two corrugated layers in a five ply structure were aligned at right angles to one another. In this case a batch, rather than continuous, process was adopted. Layers were heated in the platens for 30 seconds at 200°C and kept under light pressure until cold. The thickness was 10-11 mm, the bulk density 0.33 Kg m^{-3} and the mass per unit area 3.517 Kg m^{-2}. A photograph of the specimen, side on, is shown in Figure 14 (x4 approximately).

3.6 Speed of Throughput

In any commercial operation of the rig the greater the speed of throughput, consistent with adequate product quality, the better the economics of the process.

A series of runs was carried out in which jute cloth was coated on one side under fixed conditions but at an increasing throughput rate. The blade gap was 1.3 mm, the heater gap 1.5 mm, the, plain, roller gap 0.5 mm and the platen temperature 200°C. The speed of throughput varied from 608 to 1685 mm min^{-1}. The product was evaluated visually. The results are given in Table 2. The word 'patchy' describes areas of unmelted or partially melted powder, which, unlike the remainder of the surface, were white rather than transparent. It is possible that a reduced roller gap could have improved impregnation and allowed a good quality of feedstock to be produced at 1.5 to 2 m min^{-1}.

3.7 Felt Processing

There is interest in using a jute felt rather than cloth and consequently this was tried as a feedstock. The heated platen temperature and gap were 200°C and 3.5 mm respectively, the plain roller gap 0.5 mm, the blade gap 1.8-2.0 mm and the throughput rate 600 mm min^{-1}. It proved necessary to increase the blade gap to the upper value to avoid separating the fibres. The final thickness of the felt, coated on one side, was 1.03-1.1 mm, the polymer loading 38.7 $^w/_o$, the bulk density 0.445 x 10^3 Kg m^{-3} and the mass per unit area was increased from 0.275-0.305 Kg m^{-2} to 0.49 Kg m^{-2} on impregnation. The coating thickness varied because of inconsistency in the felt feedstock. Coating on both sides of the felt would be beneficial. One method of achieving this would be to use a carrier to transport the powder granules underneath the felt until they were compressed into it by the rollers.

3.8 The Use of PVC Water-based Emulsion

Small quantities of two of these preparations were obtained from B.F. Goodrich Ltd. (numbers 351 and 576). They were applied to jute cloth by brushing and the water allowed to evaporate. Some penetration of the cloth occurred but the samples were small in size and number and were not evaluated further. Within the period of this contract it did not prove possible to get further supplies of the emulsions.

4. TESTING

Several types of test were used to evaluate the materials produced. These included measuring the tensile strength of the jute and impregnated jute sheet, the degree of adhesion between a jute face sheet and the corrugated core and the burst strength, edge crush strength, flat crush strength and puncture resistance of a corrugated core specimen. The latter four quantities were measured by PIRA (Packaging Industries Research Association) according to the appropriate British Standards used in the packaging industry.

4.1 Tensile Strength

Tensile strength measurements were carried out at room temperature using a specimen similar to that in Courtaulds Grafil test methods 402.13, 1972. The latter calls for a specimen 150 x 10 x 2 mm waisted at the centre to give a thickness of 1 mm and with 50 mm long, plain, end tabs attached to either end. For practical reasons when using jute or jute composite the width was increased to approximately 25 mm and the waisting omitted. The results are shown in Table 3. The errors in the first three columns are standard deviations, that in the final column the standard error of a component quantity, see Topping 1962.

Impregnating the jute cloth on one side gives a substantial improvement in strength, while further treatment to the other side results in a small increase on the previous value. The function of the polyethylene matrix is to enable the fibres to act co-operatively and spread the load. The results indicate that penetration of the matrix into the cloth from one side must be right through the cloth. Presumably when the second side is treated with polymer the material either remains on the surface or fills in voids in the matrix rather than among fibres. Thus having both sides of the cloth treated with polyethylene is necessary for securing good bonding to the core but hardly so to improve laminate strength.

4.2 Peel Strength

A measure of the adhesive bond strength between an outer skin and the corrugated core was determined in a 90° peel test, UK Defence Standard DTD 5577, essentially similar to ASTM D 3167-86, for assessing the strength of an adhesive layer.

Strips of sandwich material 25.4 x 200 mm were cut and a strip of steel of the same area and 6 mm thick bonded to one face. The specimen was mounted on two 25.4 mm diameter rollers as shown in Figure 15 and part of the face skin cut away from the core after warming and arranged at 90° to the bulk of the specimen. The specimen and free part of the face skin were attached to an Instron testing machine and the load to cause further separation between the core and face skin measured. Failure occurred between the polymer and fibres, though some polyethylene could be seen adhering to the face skin that had been peeled back. The results are given in Table 4.

The results are variable, especially where the outer skin and core were attached to the lower jaw. This may have been partly due to the, presumably, more complex stressing in this case. No attempt has been made to derive a bond strength because of the large variation, and indeed uncertainty, in the area of bonding.

4.3 Bursting, Crushing and Puncture Resistance

The following tests, BS 3137 Burst Strength; BS 6036 Edge Crush; BS 4686 Flat Crush and BS 4816 Puncture Resistance, are specific to packaging materials and were carried out by PIRA, reference 4, on sandwich material supplied by AEA Technology.

To measure the burst strength the specimen, with one face fully covered with a rubber diaphragm, is sandwiched between two metal ring clamps and oil pressure applied until the specimen ruptures. The diaphragm protects the specimen from penetration or attack by the hydraulic medium. Six replicate tests were made. The edge crush test is carried out on a specimen 100 mm in length and 25 mm in depth. Ten replicates were used. The flat crush strength was determined on five samples 25 cm^2 in area. Puncture resistance is measured with a pendulum device. Various weights can be added to the profiled striker to increase the impact energy. In the present work eight replicates were tested.

The results for a three ply jute material consisting of two face sheets and a flute or corrugated core are given in Table 5. In two cases the property (flat crush strength and puncture resistance) is greater than the capacity of the measuring equipment. The average mass of the impregnated jute cloth was 1.92 Kg m^{-2}.

Comparable data for corrugated core paper board products are:

1. A double walled system consisting of 215 Kraft, 188 semichemical, 215 Kraft, 175 semichemical, 215 Kraft with a mass per unit area of 1.142 Kg m^{-2}, had an edge crush strength of 12.86 KN m^{-1}.

2. A single walled system consisting of 300 Kraft, 350 semichemical, 300 Kraft, with a mass per unit area of 1.02 Kg m^{-1}, had an edge crush strength of 11.75 KN m^{-1}.

3. A single walled system consisting of 200 Kraft, 170 semichemical, 200 Kraft with a mass per unit area of 0.61 Kg m^{-2}, had an edge crush strength of 6.46 KN m^{-1}, a burst strength of 1458 KPa and a flat crush strength of 330 KPa.

Kraft refers to a product containing up to 80% of virgin wood pulp.

Though the jute product has a greater mass per unit area than any of the above it has an edge crush strength approaching that of the doubled walled material and exceeding that of either of the single walled specimens. This coupled with its high flat crush and puncture strengths indicates a useful packaging material.

5. CONTAINER PRODUCTION

A demonstration corrugated jute board container approximately 20 x 20 x 20 cm was produced. Edges were joined with a wood adhesive. A photograph is shown in Figure 16. No attempt was made to optimise the design or heat weld the joints.

6. SUMMARY

A simple rig has been designed and built for the continuous impregnation of jute cloth with powdered polyethylene, the corrugation of the sheet produced and the production of a sandwich structure from the corrugated core and plain face sheets. The maximum throughput rate is approximately 1100 mm min^{-1}.

Impregnation on one side of the cloth with polyethylene increases the tensile strength by 44% and impregnating on both sides by 54%. The main advantage of double impregnation is to assist in bonding and possibly to reduce sensitivity to moisture.

The various parameters associated with the use of the material in packaging were measured on corrugated core samples with a mass per unit area of 1.92 Kg m^{-2}. The individual values of burst, crush and edge strength and penetration resistance were excellent, comparable with those of a high quality corrugated core paper product.

Development is still required to establish the best way of making containers from the sandwich material.

The rig, process and material have all been proved on a pilot plant scale. Further development would require the equipment to be set up in India and adapted to produce wider lengths of material.

7. ACKNOWLEDGEMENTS

Dr. D.H. Bowen is thanked for his advice and encouragement during the work.

8. REFERENCES

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3. J. Topping, Errors of observation and their treatment, Inst. of Physics, London, UK, 1962, pages 82-83.
4. PIRA International, Randalls Road, Leatherhead, Surrey, KT22 7RK, UK.

Table 1

Properties of Hostalen GR 7255P

Property	Unit	Test Method	Result
Density at 23°C	g cm^{-2} ± .002	DIN 53479, Method A	0.95
Yield stress	N mm^{-2}	DIN 53455 at 50 mm min^{-1}	24
Elongation at yield stress	%	DIN 53455 at 50 mm min^{-1}	10
Tensile modulus	N mm^{-2}	DIN 53457-2	1000
Torsion rigidity	N mm^{-2}	DIN 53447	200
Flexural creep modulus, 1 mm value	N mm^{-2}	DIN 54852-24	1150
Notched impact strength,	mJ mm^{-2}	DIN 53453	
23°C			No failure
-40°C			No failure
Vicat softening temperature	°C	DIN 53460	77

Table 2

The effect of throughput speed on singly coated jute cloth

Speed mm min^{-1}	Quality of Cloth	Cloth Thickness mm
608	Good	0.77 - 0.81
720	Good	0.75 - 0.8
822	Good	0.77 - 0.84
950	Good	0.75 - 0.78
1084	Good	0.76 - 0.8
1223	Somewhat patchy	0.77 -0.65
1370	Patchy	0.77 - 0.81
1521	Patchy	0.76 - 0.82
1685	Patchy	0.76 - 0.78

Table 3

Tensile test results for jute and jute composite specimens

Material	Thickness mm	Width mm	Failure Load N	Strength MPa
100% Jute	0.72	26.52	412	
	0.8	26.52	412	
	0.8	26.62	360	
	0.8	25.7	395	
Average	0.78±.04	26.34±.43	394.7±24	19.2±1.6
Jute coated	0.72	26.52	579	
on one side	0.94	26.52	638	
23 ^{w}/o polymer	0.74	26.62	515	
	0.87	25.22	652	
Average	0.82±.11	26.22±.67	596±63	27.7±4.7
Jute coated	0.8	26.8	647	
on both sides	0.78	29.15	594	
46 ^{w}/o polymer	0.89	26.75	706	
	0.8	26.15	692	
Average	0.82±.05	27.21±1.33	660±51	29.6±3.2

Table 4

90° Peel test results

Sample	Failure Load N	Test Mode
1	46.3	Outer skin attached to lower jaws.
	42.5	
	31.5	
	39.0	
	46.7	
	36.5	
Average	40.4±5.9	
2	53.0	Outer skin and core attached to lower jaws.
	81.0	
	68.0	
	95.5	
	93.0	
	46.8	
Average	72.9±20.4	
3	62.0	Outer skin attached to lower jaws.
	47.0	
	50.5	
	55.0	
	42.2	
	47.8	
Average	50.7±6.9	
4	118.0	Outer skin and core attached to lower jaws.
	86.0	
	83.0	
	97.8	
	83.0	
Average	93.6±15	

Table 5

Properties of three layer jute corrugated board*

Property	Mean Value	Range
Burst strength, KPa	3460	3250 - 3650
Edge crush strength, KN m^{-1}	12.5	11.8 - 14.1
Flat crush strength, KPa	>960**	Minimum > 960
Puncture resistance, J	>38**	Minumum > 38

* Also known as single wall or double face.

** Indicates that the property was greater than the measuring capability of the test equipment.

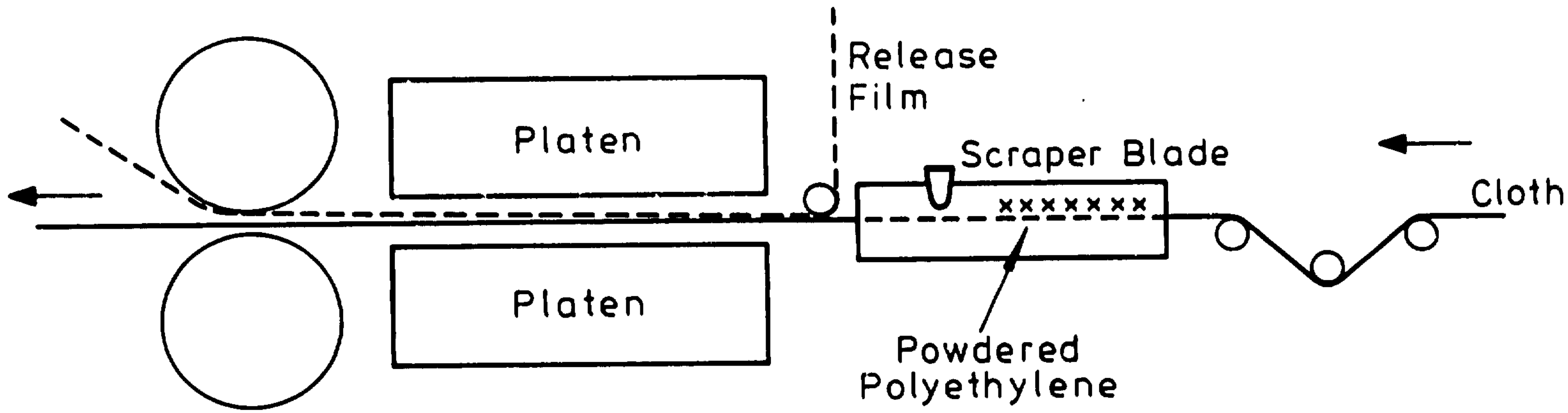

FIG. 1. JUTE IMPREGNATION RIG - SCHEMATIC SIDE VIEW

FIGURE 2   JUTE IMPREGNATION RIG

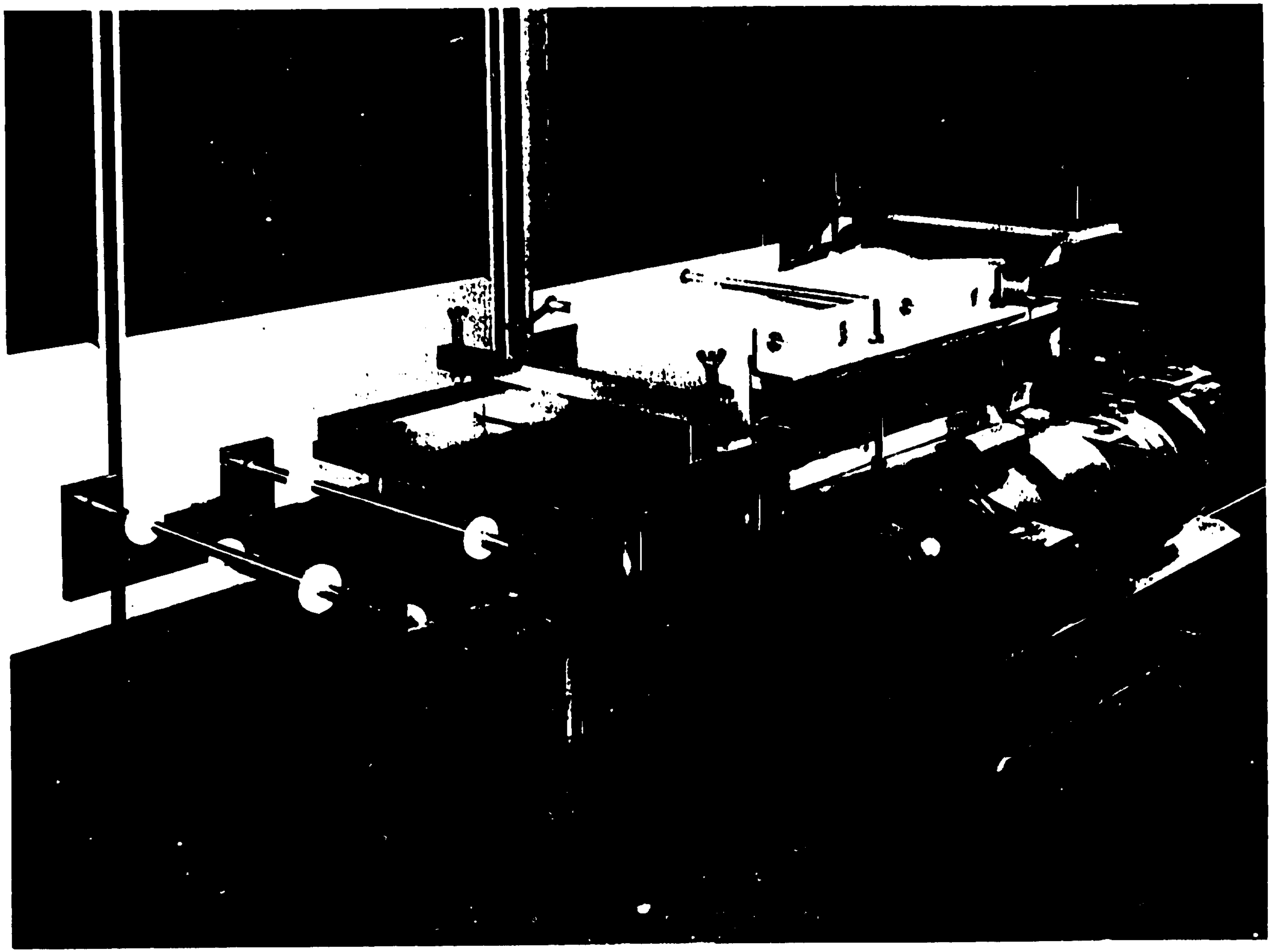

FIGURE 3 APPLYING POWDERED POLYETHYLENE

FIGURE 4 JUTE IMPREGNATION RIG WITH FEEDSTOCK

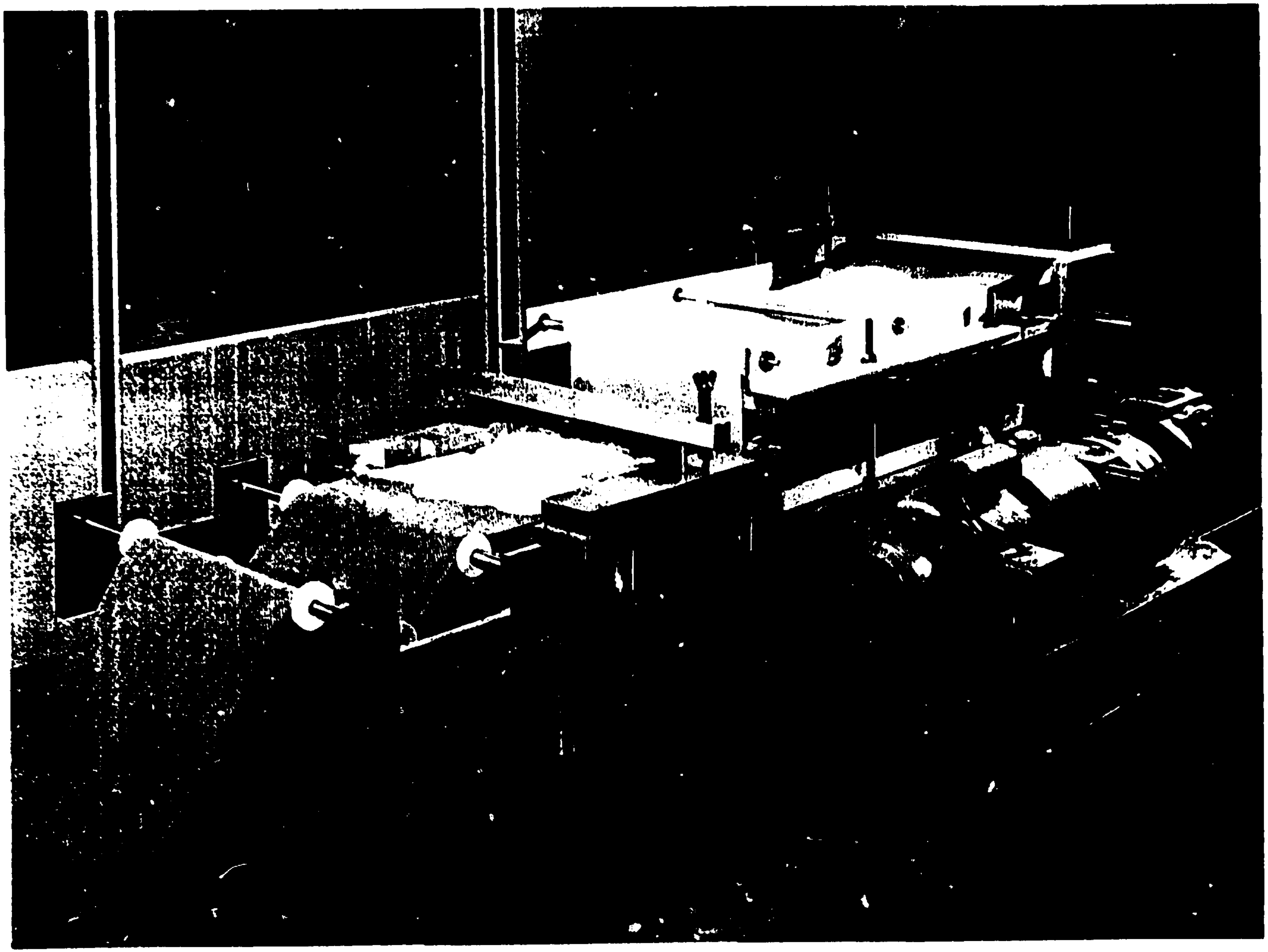

FIGURE 5 IMPREGNATION/COVERING OF JUTE CLOTH

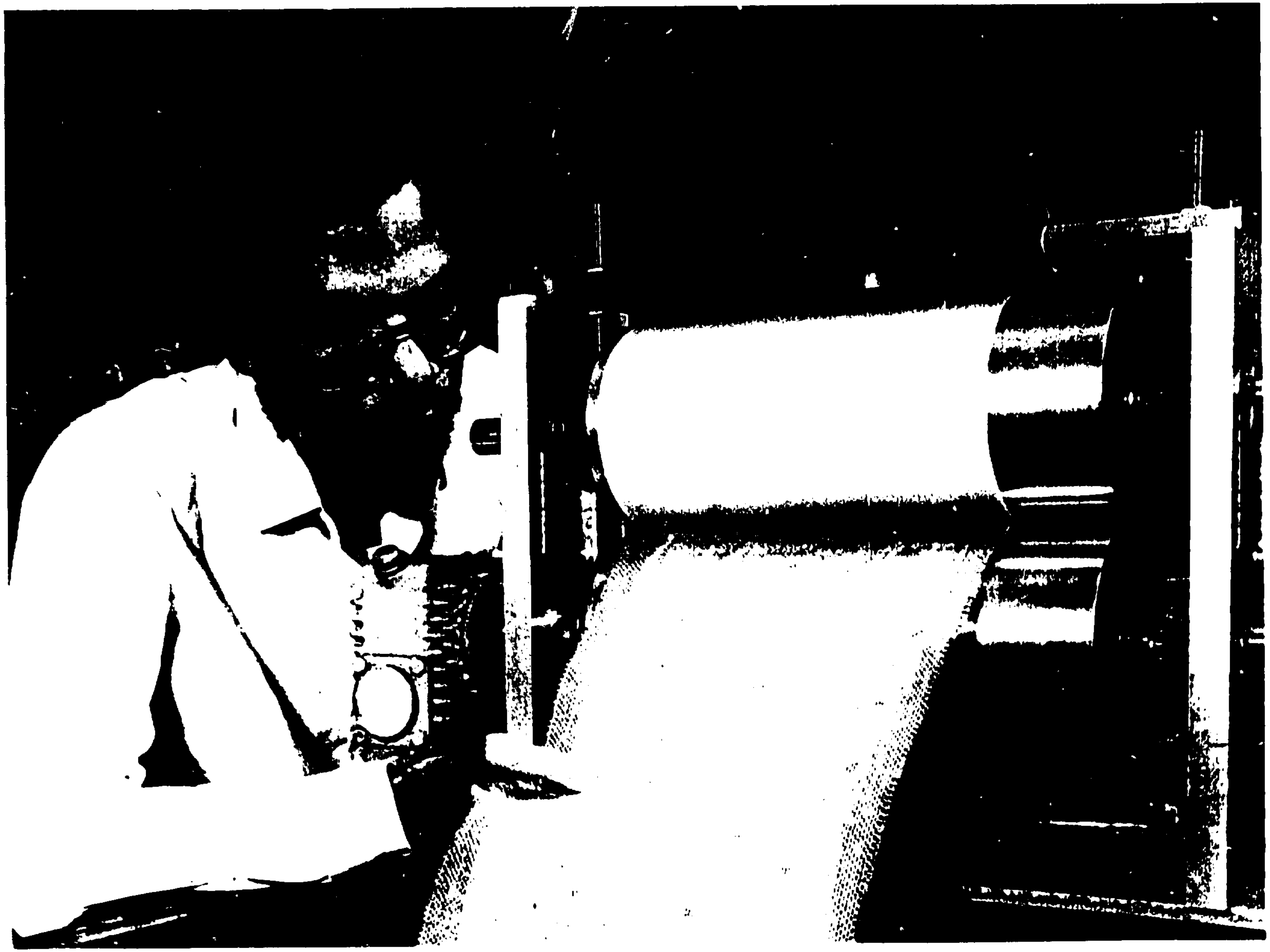

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FIGURE 6 JUTE/POLYETHYLENE (ONE SIDE)

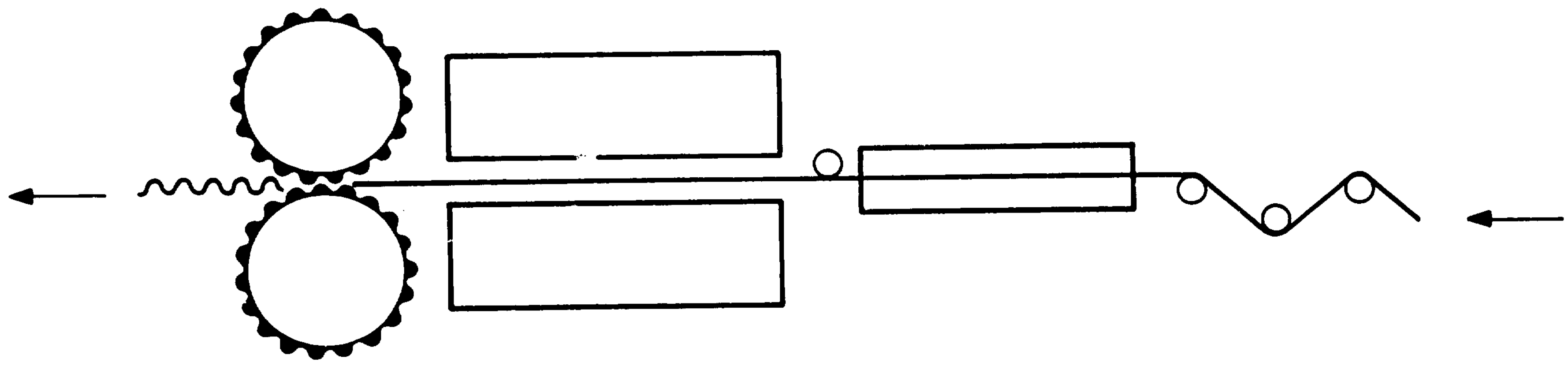


FIG. 7. JUTE IMPREGNATION RIG WITH CORRUGATING ROLLERS-SCHEMATIC SIDE VIEW

FIGURE 8 IMPREGNATED JUTE CLOTH BEING CORRUGATED

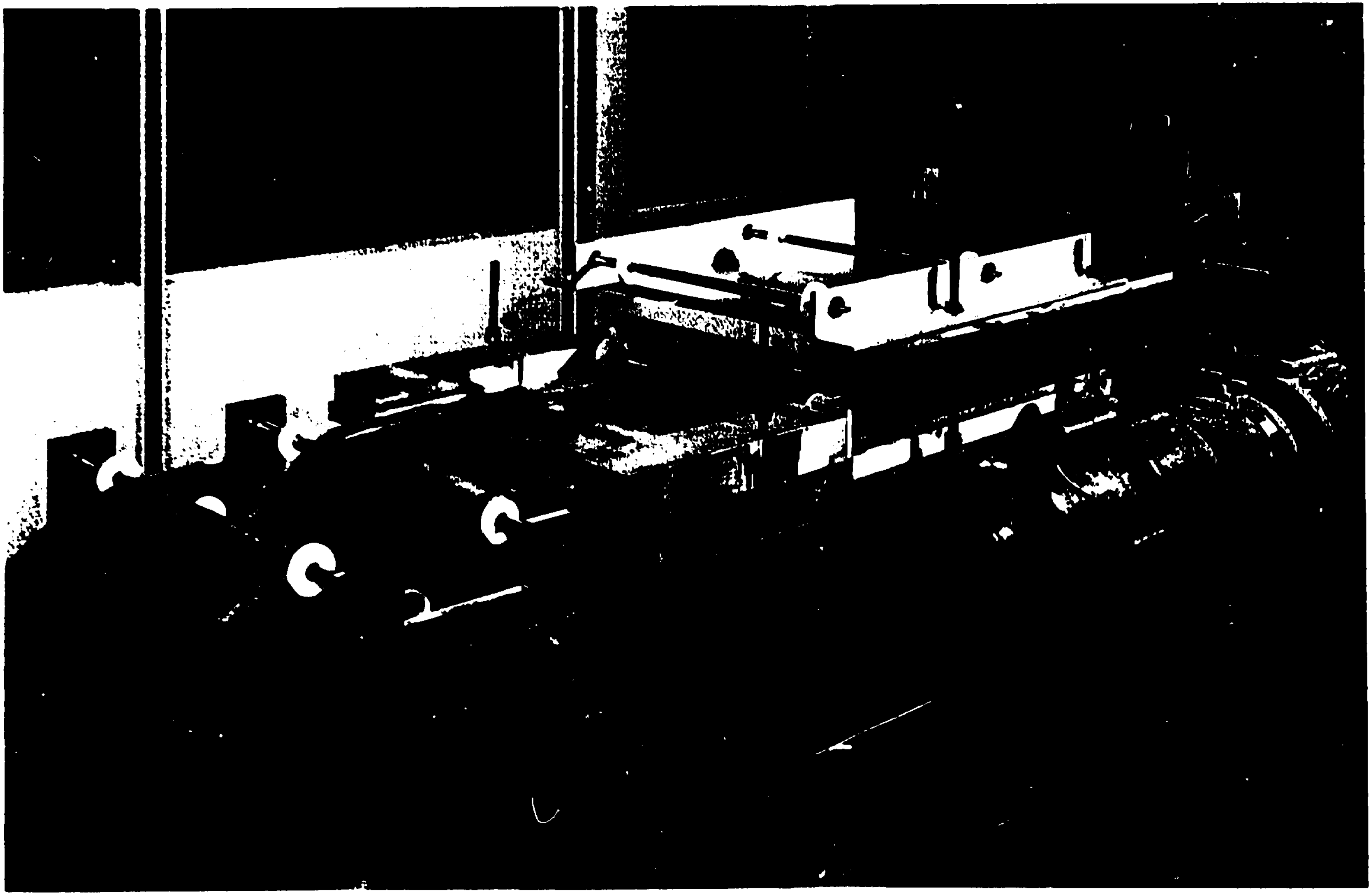
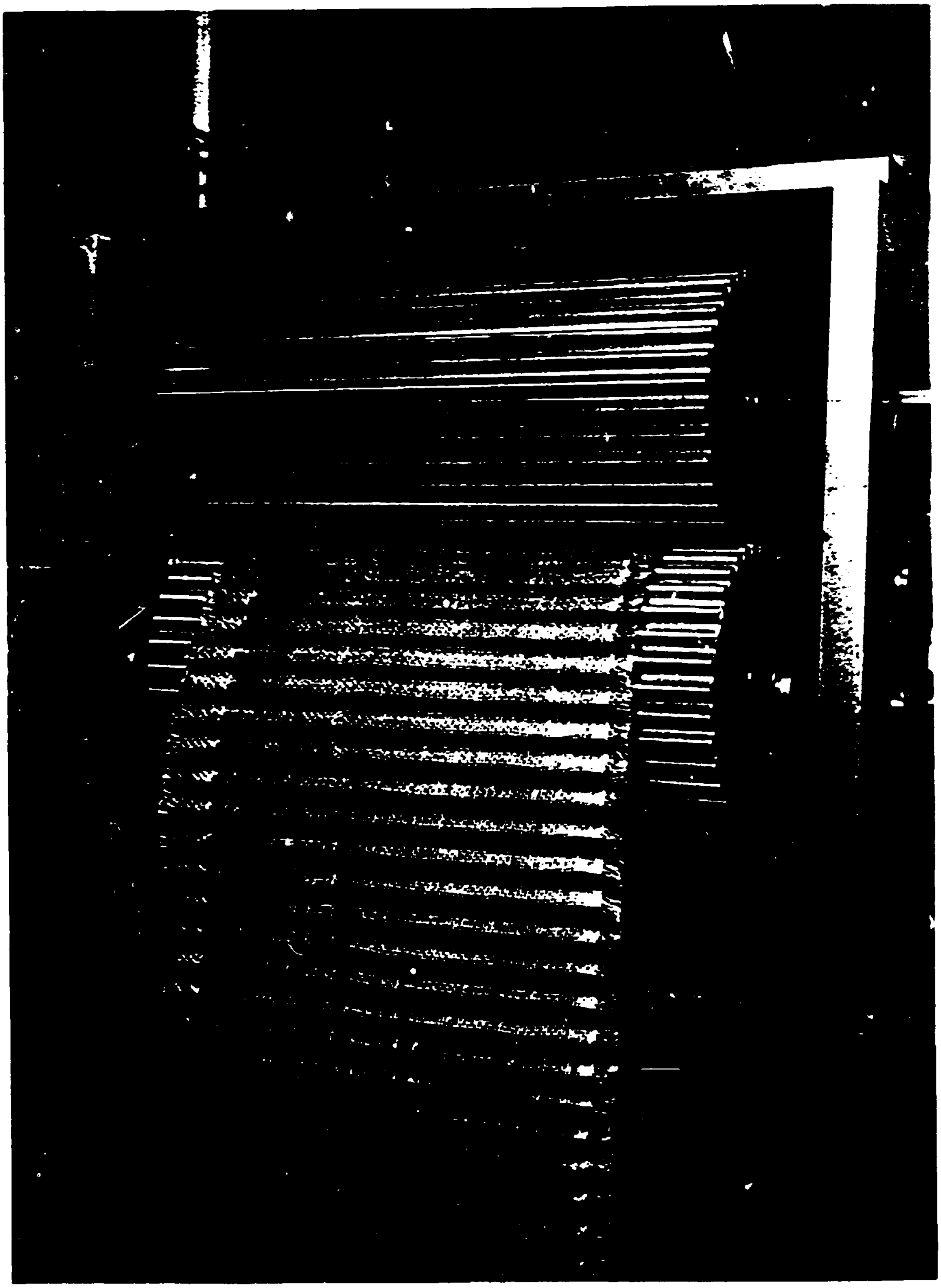


FIGURE 9 CORRUGATED JUTE CLOTH



[redacted]

FIGURE 10 JUTE CORRUGATION

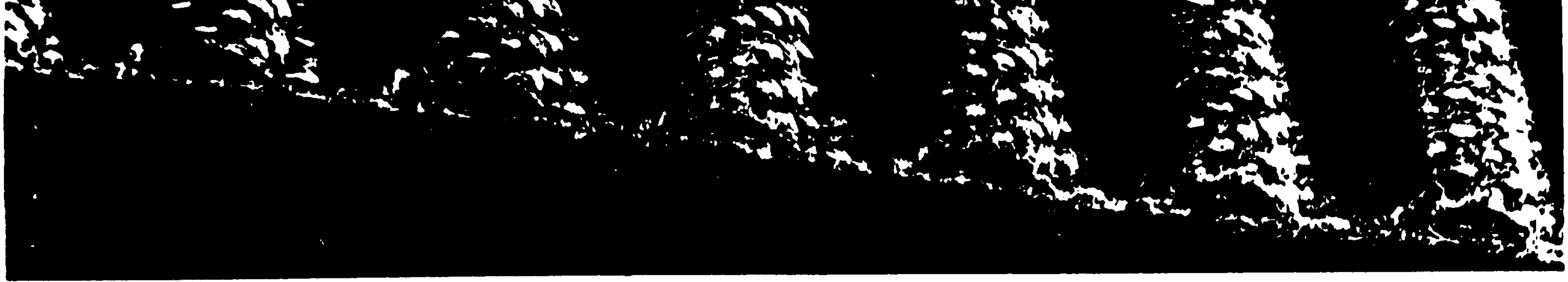


FIGURE 11 JUTE CORRUGATION + ONE LAYER JUTE

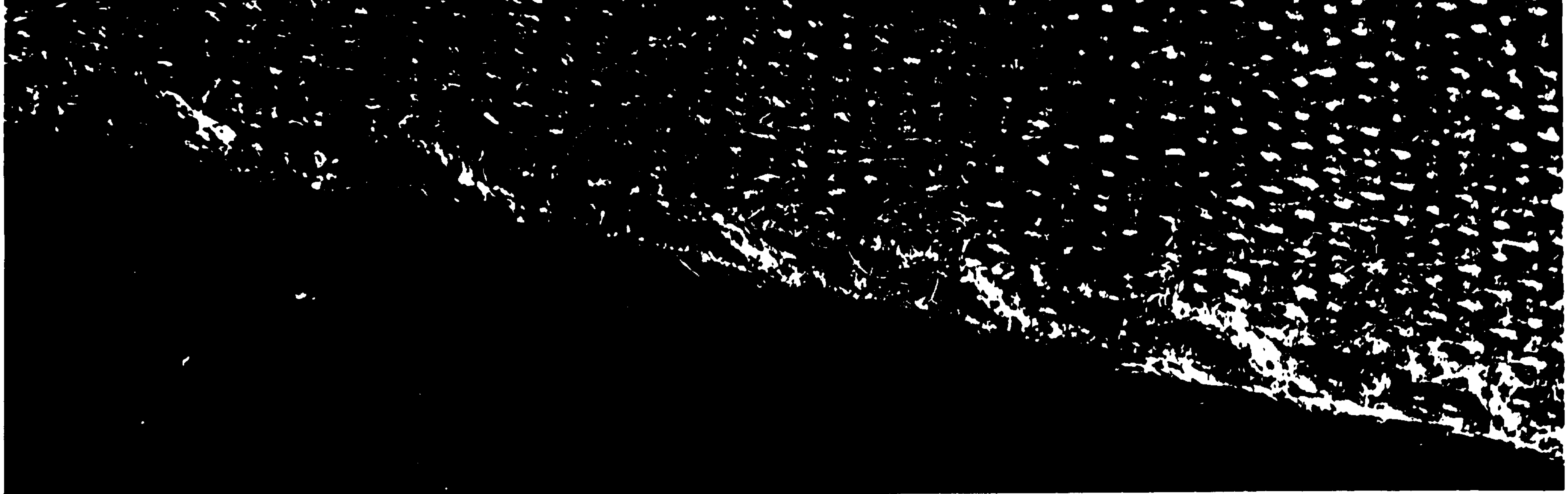


FIGURE 12 JUTE CORRUGATION + TWO LAYER JUTE

[redacted]

FIGURE 13 JUTE CORRUGATION - (5 PLY)

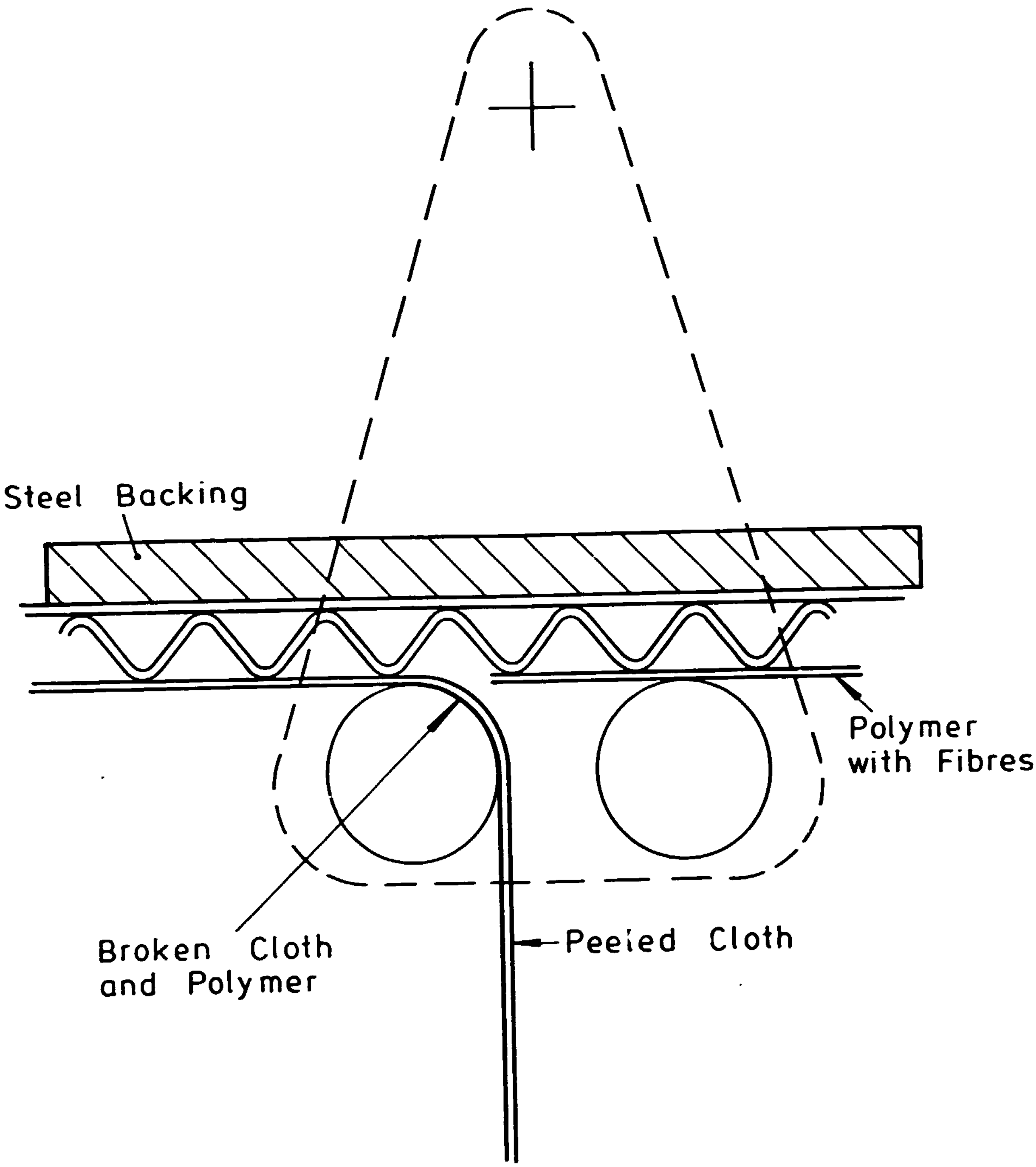


FIG. 15. 90° PEEL TEST

FIGURE

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