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JUTE REINFORCED PLASTICS FOR RIGID PACKAGING

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Materials Development Division
Harwell Laboratory

*Indian Jute Industries Research Association

July 1989

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ABSTRACT

A balanced weave jute cloth was cleaned to remove oil, dust, etc., densified by soaking in water and hot pressing and used together with phenol, urea and melamine formaldehyde resins and polyethylene and polypropylene sheet to produce test plaques. All the samples had a similar flexural modulus ~ 10 GPa, but the flexural strength of the phenolic composite, ~ 160 MPa, was two or three times greater than that of the other systems. To increase the panel stiffness a sandwich structure made from two one ply face skins and a one ply corrugated core was constructed. This was five times as stiff as a monolithic panel made from six plies of jute cloth, while the specific strength and modulus were comparable with those of a phenolic composite. The thermoset resin composites tended to behave in a brittle manner when cut and could not be formed or heat welded once cured. The polyethylene jute composite suffered from none of these drawbacks and is recommended as the best system for use in the construction of full scale packing cases. The polypropylene based composite was rejected because the minimum fabrication temperature caused charring of the reinforcement. Three model boxes were prepared from jute polyethylene composite using different fabrication routes to demonstrate the feasibility of making such units. The deflections of the bases and sides of the boxes are reported.

This work was carried out for UNIDO under contract no. 88/130/MK

Materials Development Division
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1. INTRODUCTION

Jute is a valuable cash crop in India and a useful renewable resource. The work described here was undertaken under the auspices of UNIDO and of the Indian Government. It forms part of a larger programme for diversifying the applications of jute, in this case by using jute composites as a possible replacement for plywood in tea chests and packing cases.

The objectives of the present study are two-fold:

(i) to produce jute composites using urea, melamine and phenol formaldehyde resins and polyethylene and polypropylene polymers and to measure the basic mechanical properties of the composites. This will enable the best matrix system to be identified and will provide design data.

(ii) to consider the design of rigid packaging made from jute composite and to study, conceptually, a manufacturing route for the product.

2. MATERIALS

2.1 Reinforcement

The jute fabric used was a balanced weave containing 6 picks per cm in both warp and weft directions. The areal density was 294 g m^{-2}. The oil content was believed to be of the order of 1%.

2.2 Treatment of the Reinforcement

It is usual to treat the jute cloth prior to use to remove any batching oil, dust or other contaminants that might interfere with matrix/reinforcement bonding.

Three treatments were used:

(i) Washing in a detergent. The jute was washed in a 2.5% solution of Janitol in hand hot water for 60 minutes with occasional agitation. The fabric was rinsed in hand hot water until no suds appeared and the rinse water was clear. After draining the jute was dried in an oven at 100°C.

(ii) Immersion in Genklene. The cloth was immersed in Genklene for 4 hours, with occasional agitation, and then dried in an oven at 100°C.

(iii) Degreasing in Triklone (trichloroethylene). The cloth was put in a degreasing chamber containing Triklone for one hour and then dried at 100°C.

After cooling in a desiccator samples were weighed and the weight loss on treatment determined. The percentage weight losses for treatments (i) to (iii) were 6.5, 9.0 and 9.4% respectively. The Triklone treatment removed the greatest amount of contaminant and was the most convenient and was subsequently used to treat the majority of samples of jute cloth used in this work.

2.3 Densification of the Reinforcement

It had been noted previously, Bowen et al (1981), that steam consolidation improved the jute content of the composites and thus increased the mechanical properties, and because less resin was used, decreased the costs. The process was applied in the present studies.

Precleaned cloth was soaked in 'Analar' water until saturated and the excess water drained off. The cloth was placed between two Duralumin plates located within the plattens of a press heated to 150°C. A pressure of 2 MPa was applied for 5 minutes. This treatment changed the fibre finish from rough to satin as well as densifying the cloth. It is not known whether the same results would be obtained by simply heating and pressing.

Three samples of cloth of an average thickness of 0.77 mm and an average weight of 140 g were subjected to this treatment. The thickness was reduced by an average of 50% with an average weight loss of only 2%.

2.4 Matrix Materials

The full details of the matrix materials used are given in Appendix 1. It should be noted that the polyethylene film produced by British Visqueen is fully food compatible, while the other polymer films are almost certainly safe to use with food. Formaldehyde based resins, however, should, under no circumstances, be used in such a way that they come into contact with foodstuffs, without approaching the manufacturer and getting their written approval that it is safe to do so first.

The lowest priced thermoset resin in India appears to be urea formaldehyde at Rs 17,000 p.t. compared with Rs 40,000 p.t. for phenol formaldehyde resin and Ps 37,000 p.t. for the two thermoplastics.

3. FABRICATION

Samples were prepared from the phenol formaldehyde resin and suitably treated jute cloth by preparing a stack consisting of a piece of non-porous peel ply material, six sheets of jute and another piece of peel ply. 20 g of powdered resin were spread between each of the seven pairs of surfaces. The sandwich was heated for 5 minutes at 120°C and then pressed at 6.9 MPa and 150°C. The temperature was maintained for 15 minutes after the mould temperature had stabilised. The specimen was cooled under pressure.

Apart from being cheaper, the urea and melamine formaldehyde resins used here were fully or partly soluble in water which made fibre impregnation easier. The two urea formaldehyde systems are fully soluble in water and 96 g of W481 in 300 ml of water or 95 g of W436 in 250 ml of water were used to make impregnating solutions. Layers of treated jute cloth were soaked overnight and allowed to dry at room temperature. Forced drying was avoided as this tended to initiate curing. The rough, stiff, dry sheets were placed in a released mould

and pressed at 6.9 MPa and 130°C for 20 minutes. The melamine formaldehyde system is soluble in a mixture of water and methylated spirits. Initially 71 g of resin were added to 250 ml of methylated spirit and then 250 ml of water added. The rest of the fabrication procedure, including curing, was as described above for urea formaldehyde composites.

Thermoplastic based samples were made by a film stacking technique. The stacking sequence was 3, 1, 3, 1, 3, 1, 2, 1, 3, 1, 3, 1, 3 where 1 refers to one layer of jute cloth and 2 or 3 to two or three layers of polyethylene or polypropylene. The sandwich was placed in a steel mould and pressed at 6.9 MPa and, for polyethylene, 130°C. The temperature was maintained for 15 minutes once the mould temperature had stabilised and the specimens were cooled under pressure. The British Visqueen polyethylene film was found to delaminate internally when used in this way presumably because of its thickness. When using polypropylene it was necessary to raise the processing temperature to 180°C and although the dwell time was reduced to 5 minutes the jute fibres began to degrade. The odour of charred fibre could be detected near the surface of the sample for some weeks after fabrication.

Most composite samples were in the form of monolithic plates made from six plies of cloth. An alternative construction is a sandwich panel made from a one ply corrugated core with two, one ply thick, face panels attached. Some simple details of the design of sandwich panels are given in Appendix 2.

To prepare the corrugated core using a urea formaldehyde resin an impregnated and partially dried sheet of composite was used together with a steel mould with a corrugated surface. The details of the corrugations are: height 4.7 mm, pitch 6.7 mm, upper radius 2.4 mm, lower radius 3.2 mm and angle of slope 65°. The sheet was fed onto the mould and 6.35 mm diameter steel rods pressed sequentially into the sheet. When the sheet completely covered the mould it was pressed and cured as described previously. Failure to carry out the operation sequentially caused the composite sheet to fail because it was unable to strain sufficiently to conform to the corrugations. The face sheets were affixed one at a time using extra resin on the crests of the

corrugations and 4.5 mm diameter steel rods in all troughs as a support. When the faces were cured in position the rods were removed. Thermoplastic corrugated samples were prepared in a similar manner with extra thermoplastic added to aid adhesion.

4. EXPERIMENTAL MEASUREMENTS AND RESULTS

4.1 Photographs of Samples

Figure 1 shows cleaned, densified and undensified jute cloth. A typical resin laminate plate containing six plies of fibre is shown in Figure 2. Corrugated sandwich structures are illustrated in Figures 3 and 4. The more open nature of the urea formaldehyde jute skin is clear in the latter figure.

Micrographs of various composite samples are given in Figures 5 to 11. In all cases the reinforcement has been cleaned in Triklone and the magnification is x40. Figures 5 and 6 show the difference between undensified and densified material respectively in a phenolic resin matrix. The better fibre packing in the latter case is clear. Composites based on urea formaldehyde are shown in Figures 7 and 8. In both cases the fibre has been densified but in the former case the resin was oven dried. Because this caused partial resin cure the material is less well compressed than that in Figure 8, though in this case the composite has cracked internally. A melamine formaldehyde resin sample, which was oven dried, Figure 9, also shows considerable voidage. Thermoplastic based composites are illustrated in Figures 10 and 11.

4.2 Experimental Measurements

Flexural strength and modulus were measured at a span to depth ratio of 16:1. For monolithic plates 10 mm wide specimens were used, but for corrugated core materials the width was 25 mm. Specimens were cut in the two principal fibre directions of the cloth reinforcement or along and at right angles to the direction of corrugation.

4.3 Results and Discussion

4.3.1 Effects of consolidation

Some details of the effects of steam consolidation and matrix type on the fibre weight loading of 6 ply plates are given in Tables 1 to 3. Weight rather than volume loadings are given as these were measured directly. Converting to a fibre loading is not simple because of the, possibly, high void content of the composites. Consolidation increases the fibre weight loading of a phenol formaldehyde specimen by 10%. Values for urea and melamine formaldehyde specimens using consolidated fibre are similar to those for similar phenol formaldehyde material. The fibre weight loading for consolidated fibre in polyethylene is similar to that for thermoset resins but slightly less than for a polypropylene matrix. Details of the areal and bulk densities of the corrugated core sandwich panels are given in Table 4. The bulk density compared to that of a monolithic plate is reduced by a factor of between 5 and 6.

4.3.2 Mechanical properties of monolithic sheet

The flexural modulus and strength properties are summarised in Table 5. Values for the phenolic and urea formaldehyde UF W436 systems are based on 10 readings, the remainder on 5 readings. All reinforcement was steam consolidated and, except for the first two entries, for phenolic resin, had been washed in Triklone. Apart from the first pair of results for UF W436 there appears to be little difference between properties measured in orthogonal directions provided the samples are from the same plate. This is as expected for a balanced reinforcement. Some of the lowest results are for urea and melamine formaldehyde based systems and it should be recalled that difficulties due to the type of drying after impregnation and obtaining an impregnating solution were more severe in these cases than for the other materials. The best all round results were for the phenol formaldehyde resin composites and in this case having the fibre washed or unwashed made no signficant difference to the results. Specimens based on polypropylene had the highest modulus but only half of the flexural strength of the phenolic composites. This may be due to fibre damage

caused by the relatively high processing temperature for polypropylene or, more likely, by the inability of the polymer to penetrate the fibre structure.

It is not easy to deduce definitive properties for jute fibres because measurements are so sensitive to the filament diameter and constitution. Pal (1989) quotes a modulus of 45 GPa and indicates that the ultimate strength lies between 550 and 600 MPa. On the basis of these figures and the fibre contents given in Table 5 the maximum modulus and strength obtained here are less than half of those predicted. This indicates that the various matrices are not penetrating into the structure of the individual jute filaments in such a way as to wet out the ultimate cells which combine to make a filament, and that in some cases that processing may be damaging the filaments. It is perhaps not surprising that the powdered resin and thermoplastics did not penetrate the structure fully but the water or semi-water soluble urea and melamine formaldehyde systems would have been expected to yet these materials did not exhibit improved properties. Possibly the resins were too dilute and multiple impregnation is required or the subsequent drying to remove water disrupted the fibre structure.

It is instructive to compare the results of Table 5 with those for a sample of 5 ply plywood, Wells et al. (1979). If the grain of the top and bottom plies is in the direction of the long axis E_f = 8.3 GPa and σ_f = 80 MPa, while if the grain direction is at right angles to the long axis E_f = 2.8 GPa and σ_f = 34 MPa. The phenol and urea formaldehyde systems tested here are superior to plywood and unlike the latter are isotropic, and the thermoplastic matrix system is comparable to the 5 ply board.

4.3.3 Mechanical properties of corrugated core materials

Specimens based on a polyethylene matrix were used. Samples with the corrugations in the direction of the long axis were of such a width that approximately three half wavelengths of the corrugated core were loaded (Figure A1 shows one, idealized, half wavelength of core). The results, based on 4 readings, are given in Table 6. The modulus is considerably less than that of a monolithic plate but the strength, when loading is at right angles to the corrugations, is similar to that for a

monolithic polyethylene composite. The stiffness of the section is defined as the product of the modulus and moment of inertia of the beam. Using average thicknesses and moduli for polyethylene composites quoted in the various Tables the ratio of the stiffness of the sandwich beam to that of the monolithic plate is 5.3:1. If the much lower specific gravity of the sandwich beam is taken into consideration the specific properties of the latter (i.e. the modulus and strength divided by the specific gravity) are excellent, being 10.8 GPa and 189 MPa, respectively, for loading at right angles to the corrugations.

The simple analysis, see Appendix 2, can be used to predict failure for loading at right angles and parallel to the corrugations. In the former case it was observed that the corrugations buckled (i.e. element PB in Figure A1), while in the latter case the surface skin between two successive internal support points failed (i.e. 2PR in Figure A1). Equations (d) and (c) of the Appendix apply respectively. X = 6.5 mm, d = 0.46 mm, H = 4.5 mm and E = 9 GPa. Substituting the appropriate values in equation (d) gives a predicted buckling load of 100 MPa against an observed value of 47 MPa. The discrepancy is probably due to the fact that the real strut, PB, was not straight as assumed, but part of a sine curve. This would clearly reduce the buckling load. The observed failure load for stressing parallel to the corrugations was approximately 1 kg and b = 25 mm. Substituting in equation (c) indicates a failure stress of 0.2 MPa as against an observed value of 22 MPa. The reasons for this large discrepancy are not clear. Two possibilities are, firstly, that the skin was not firmly bonded at support points and so a larger value of X should have been used; secondly, and rather more likely, the stressing was such that after a small skin deflection a type of buckling failure occurred rather than the flexural mode assumed theoretically. It should be noted however that although quantitatively incorrect the analysis predicted in accordance with experiment that failure would occur in the skin rather than the corrugation strut PT.

4.4 Summary

The primary aim of this study is to identify a jute based composite suitable for making packing cases for tea, apples, etc. The final

materials choice is dependent on both test plaque properties and the ease of using these materials in the fabrication of containers.

The work reported here has shown that the best mechanical properties are obtained with a thermoset phenol formaldehyde resin. The use of a urea formaldehyde system gives materials with as good a modulus as the phenolic composites but only half the flexural strength. However the latter resin is half the price of the phenolic and, being water soluble, fabrication is easier. The disadvantages of the urea based system are brittleness, that it cannot be post formed and that extra adhesive is needed for joining. Thus, although it can be cut by guillotining, this causes considerable edge damage and delamination, and shaped corner pieces must be specially moulded.

The thermoplastic polyethylene based system can, unlike jute polypropylene composite, be produced at a low enough temperature to avoid fibre degradation, has a modulus similar to that of the thermoset jute composites, but a rather lower strength. It has two advantages for box making; the material can be heat formed and heat welded without the addition of extra material. It is for these reasons that the jute polyethylene material has been selected for further studies on the production of packing cases.

4.5 Production and Performance of Model Boxes

Three jute polyethylene composite model boxes, shown in Figure 12, were produced. Each consisted of a base and four sides but no top. Box A had a base 100 x 100 mm and sides 140 x 100 mm. The six ply composite, 1.8 mm thick, was mechanically attached to a 7 x 7 mm wooden framwork. Box B had a 110 x 100 mm base and 150 x 110 mm sides. It was made from 3 ply material approximately 1 mm thick. The four sides were joined internally by 25 mm wide, 1 mm thick, composite angle pieces running the length of the structure, while the base was joined to the sides by similar angle pieces applied to the exterior of the box. Box C had a 150 x 150 mm base and 150 x150 mm sides all made from 3 ply composite, 1.1 mm thick. The perimeter was made from two part-formed sheets of composite with two internal strips welded into place to cover the butt joins. The base was made oversize by 40 mm and cut, shaped and

heat welded onto the sides. The skirt of the base overlapped the sides externally.

The three boxes were tested by loading with a 12 mm diameter ball pressed into the centre of the base, the centre of each of the four sides and approximately 20 mm in from the free or top edge of each side and on the centre line. In each case the cross head deflection was measured as a function of load. The results are summarised in Table 7. To aid comparability, deflections for similar loads are quoted where possible.

The results are much as would be expected. In each case the base, having four supported edges, deflects less than a side. Box A is everywhere much stiffer than the other two because the composite is thicker, the dimensions smaller and each panel is fastened to a rigid frame and hence has four supported edges. The results for positions 2 to 5 are rather greater than for the base, position 1, because the span involved has been increased from 100 to 140 mm. Box B shows similar deflections of a base and of sides at the centre as Box A but for only one fifth of the load. The deflection of the sides on the centre line but near the open top (centre edge) are much greater than elsewhere because the fourth edge is unsupported. The results for Box C are similar.

It is possible to calculate the deflection of a plate with three edges built in and one free, or all four built-in, Timoshenko and Woinosky-Krieger (1959), but the solution is in terms of a complicated summation of hyperbolic quantities and the approach will not be pursued here.

These studies are of a preliminary nature and merely illustrate the possibility of making small boxes in different ways with jute polyethylene composite. An obvious source of improvement would be to fold over the top edges of each side to increase the section thickness and hence stiffness, while the addition of a close fitting top would considerably reduce the shear distortion of the whole structure.

5 CONCLUSION

The present study has identified means of producing jute reinforced thermoset and thermoplastic matrix composites. The highest properties are obtained from treated and densified jute cloth with a phenolic resin matrix. A similar modulus is obtained using urea formaldehyde resin or a polyethylene matrix but in neither case is the flexural strength as high as that obtained with a phenolic resin. A three ply sandwich structure with a corrugated core was made and tested. The stiffness is 5 times that of monolithic plate and the specific properties comparable. Thermosetting resin matrix composites tend to be brittle and cannot be heat formed or joined once the resin has been cured. A thermoplastic based composite is much more pliable, and can be post formed and joined by the application of heat and pressure. It is suggested that future work is carried out with jute polyethylene composites. Some simple model box structures based on various types of fabrication route have been made to demonstrate the feasiblity of making full scale jute polyethylene composite packing cases.

6. RECOMMENDATIONS FOR FUTURE WORK

Having demonstrated the conceptual feasibility of a jute composite packing case a second programme should concentrate on the economic fabrication of the units. Among the points to be addressed, in conjunction with IJIRA, are the following:

- The selection of the optimum type of jute reinforcement.
- The economics of using jute prepared with a small quantity of vegetable oil which may enable the washing/cleaning stage to be omitted.
- The calendering or hot pressing ofjute to produce densification without the need for a water soak.
- The optimisation of the amount of polyethylene in the composite.

- The possibility of printing on the outer surface of a jute composite or incorporating ready printed material in the laminating process.

- Methods of continously producing composite sheet.

- The design of a full size packing case including a top.

- Economic cutting of continuous sheet to produce a flat former for a packing case.

- The design of rigid composite corner fittings and the attachment of these to the bottom and sides by stapling or autogenous welding.

- Testing of full-scale packing cases and of a stack of these.

At the end of the contract the aim would be to specify a pilot plant for the production process, which could be set up in India.

7. ACKNOWLEDGEMENTS

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Table 1

Effect of steam consolidation on the characteristics of jute/phenolic test pieces

Fabric Treatment	Plate Thickness mm	Fibre Content $^{w}/_{o}$	Plate Density 10^{3} kg m^{-3}
Unconsolidated	2.05	55	1.39
Consolidated	1.79	66	1.49

Table 2

Comparison of plate characteristics using consolidated fabric with UF and MF resins

Resin System	Plate Thickness mm	Fibre Content $^{w}/_{o}$	Plate Density 10^{3} kg m^{-3}
W436 uncatalysed UF	2.10	62	1.38
W481 catalysed UF	2.15	61	1.31
BL434 uncatalysed MF	2.30	66	1.11

Table 3

Composition of jute fibre reinforced thermoplastic plates

Matrix Material	No. of Layers of Fabric	No. of Layers of Film	Plate Thickness mm	Fibre Content w/o	Plate Density 10^3 kg m^{-3}
Polyethylene	6	20	2.06	64	1.20
Polypropylene	6	21	1.81	72	1.22

Table 4

Details of corrugated core sandwich panels

Matrix Material	Panel Thickness mm	Panel Area Density kg m^{-2}	Panel Bulk Density 10^3 kg m^{-3}
Urea formaldehyde W481	6.2-7.5	1.64	0.24
Polyethylene	5.2-5.5	1.35	0.25

Table 5

Mechanical properties of jute composites

Resin	Treatment	Direction	W_f, %	E_f, GPa	σ_f, MPa
Phenolic J1041 H	Unwashed	0	65	10.6 ± 1	163 ± 9
"	"	90	"	10.4 ± 0.5	156 ± 9
"	Washed	0	"	10.8 ± 1.2	161 ± 14
"	"	90	"	11.6 ± 0.4	164 ± 7
UF W436	"	0	"	5 ± 0.3	38 ± 12
"	"	90	"	7 ± 0.6	71 ± 7
UF W436	"	0	60.8	11.9	121
UF W481	"	0	59.8	10.4 ± 0.8	83 ± 9
"	"	0	61.8	8.7 ± 1.2	74 ± 7
"	"	90	61.8	10.8 ± 0.8	88 ± 7
MF BL434	"	0	65.8	4.8 ± 2.2	41 ± 9
"	"	0	-	7 ± 2.2	56 ± 14
Polyethylene 50 µm	"	0	64	9.6 ± 1.8	58 ± 4
"	"	90	64	8.3 ± 1.8	53 ± 1
Polypropylene 20-35 µm	"	0	72	14.4 ± 1.9	67 ± 2
"	"	90	72	13.9 ± 1.1	57 ± 1

Table 6

Properties of corrugated core sandwich materials, based on jute polyethylene composite

Direction	E_f, GPa	σ_f, MPa
Along the corrugation length	2.7 ± 0.2	47 ± 3
At right angles to the corrugation length	1.9 ± 3	22 ± 3

Table 7

Deflection of the bottom and sides of jute polyethylene boxes

Box	Dimension of panel, mm	Number	Position	Load, kg	Deflection, mm
A	100 x 100	1	Centre	2.5	0.4
A	140 x 100	2	Centre	2.5	0.5
A	140 x 100	3	Centre	2.5	0.6
A	140 x 100	4	Centre	2.5	0.5
A	140 x 100	5	Centre	2.5	0.55
A	140 x 100	6	Centre/edge	2.5	0.6
A	140 x 100	7	Centre/edge	2.5	0.25
A	140 x 100	8	Centre/edge	2.5	0.35
A	140 x 100	9	Centre/edge	2.5	0.35
B	110 x 110	1	Centre	0.5	0.35
B	150 x 110	2	Centre	0.5	0.5
B	150 x 110	3	Centre	0.5	0.5
B	150 x 110	4	Centre	0.5	0.45
B	150 x 110	5	Centre	0.5	0.55
B	150 x 110	6	Centre/edge	0.5	1.3
B	150 x 110	7	Centre/edge	0.5	1.1
B	150 x 110	8	Centre/edge	0.5	1.25
B	150 x 110	9	Centre/edge	0.5	1.45
C	150 x 150	1	Centre	1.0	1.2
C	150 x 150	2	Centre	1.0	2.1
C	150 x 150	3	Centre	1.0	2.1
C	150 x 150	4	Centre	1.0	1.85
C	150 x 150	5	Centre	1.0	1.7
C	150 x 150	6	Centre/edge	0.5	1.1
C	150 x 150	7	Centre/edge	0.5	1.6
C	150 x 150	8	Centre/edge	0.5	1.25
C	150 x 150	9	Centre/edge	0.5	1.6

APPENDIX 1

Material Supplies

Phenol formaldehyde resin

Cellobond ground phenolic resin powder J1041 H — This resin contains a quantity of hexamine as catalyst

BP Chemicals Ltd. Tel: 0446 731000
Sully, Penarth,
South Glamorgan CF6 2YU

Urea-formaldehyde resin

Urea-formaldehyde resin (uncatalysed) water soluble - W436

Urea-formaldehyde resin (catalysed) water soluble - W481

Melamine-formaldehyde resin

Melamine-formaldehyde resin (uncatalysed) - BL434

Both the u.f. and m.f. resins are produced by:

B.I.P. Chemicals Ltd., Tel: 021 552 1551
P.O. Box 6,
Popes Lane,
Oldbury, Warley,
West Midlands B69 4PD

Polypropylene

Propafilm extruded film MG3055 20-35 μm thick

I.C.I. plc, Tel: 07073 23400
Plastics Division,
P.O. Box 6,
Bessemer Road,
Welwyn Garden City AL7 1HD

Polyethylene

Polyethylene lay-flat tubing. Film thickness 50 μm

Porter Chadburn Plastics Ltd.,
Lilly Hall Trading Estate,
Workington,
Cumbria.

Polyethylene film. Film thickness ∿ 300 μm (1000 gauge)

Manufacturer - British Visqueen Ltd.

Supplier:-
UBM Supplies (Central) Ltd.,
1 Aristotle Lane,
Off Kingston Road,
Oxford.

APPENDIX 2

The design of a sandwich beam

Consider the symmetric repeat unit shown in Figure A1. Because in practice the structure is subject to a distributed load the panel is assumed to carry a load W per unit length and width. The bracing struts have been taken as linear rather than sinusoidal for convenience, and in the analysis a worst case situation has been taken with the load concentrated at the mid points of parts of the structure.

A load Wx acts vertically downward through the middle of the strut PB. This leads to a compressive stress in the member

$$\sigma_c = \frac{Wx \cos \theta}{bd} \qquad (1)$$

where b and d are the breadth and depth of the strut respectively and a force

$$Wx \sin \theta$$

at right angles to the strut. The latter can be considered as a double encastré beam. The maximum bending moment, M, in this due to the force Wx sin θ applied at the centre is

$$\frac{Wx \sin \theta \ . \ x \operatorname{cosec} \theta}{8} = \frac{Wx^2}{8} \qquad (2$$

see Harris (1959) for instance. The bending stress, σ_{b1}, due to this moment is given by

$$\sigma_{b1} = \frac{Md}{2I}$$

where $I = \frac{1}{12} bd^3$, or

$$\sigma_{b1} = \frac{3Wx^2}{4bd^2} \qquad (2)$$

Now consider the upper surface. PR is half of another double encastré beam with a force 2Wx acting through R, the mid point. In this case

$$M = \frac{Wx^2}{2}$$

and the maximum stress, σ_{b2}, occuring at R is given by

$$\sigma_{b2} = \frac{3Wx^2}{bd^2} \qquad (3)$$

Finally, the strut PB is subject to a buckling load. Taking it as a beam with built-in ends the critical load, below which buckling does not occur, is

$$W_{cr} = \frac{4\pi^2 EI}{(PB)^2}$$

or

$$\sigma_{cr} = \frac{4\pi^2 Ed^2}{12(PB)^2} = \frac{4\pi^2 Ed^2}{12(X^2 + H^2)} \qquad (4)$$

Thus in analysing the behaviour of the structure the following four conditions must be considered:

(a) $\sigma_c = \frac{Wx \cos\theta}{bd}$

(b) $\sigma_{b1} = \frac{3Wx^2}{4bd^2}$

(c) $$\sigma_{b2} = \frac{3Wx^2}{bd^2}$$

(d) $$\sigma_{cr} = \frac{4\pi^2 Ed^2}{12(X^2 + H^2)}$$

With specific values for the various materials and geometric constraints the equations can be used to design a sandwich beam. Alternatively they can be used to account for the behaviour of a given structure.

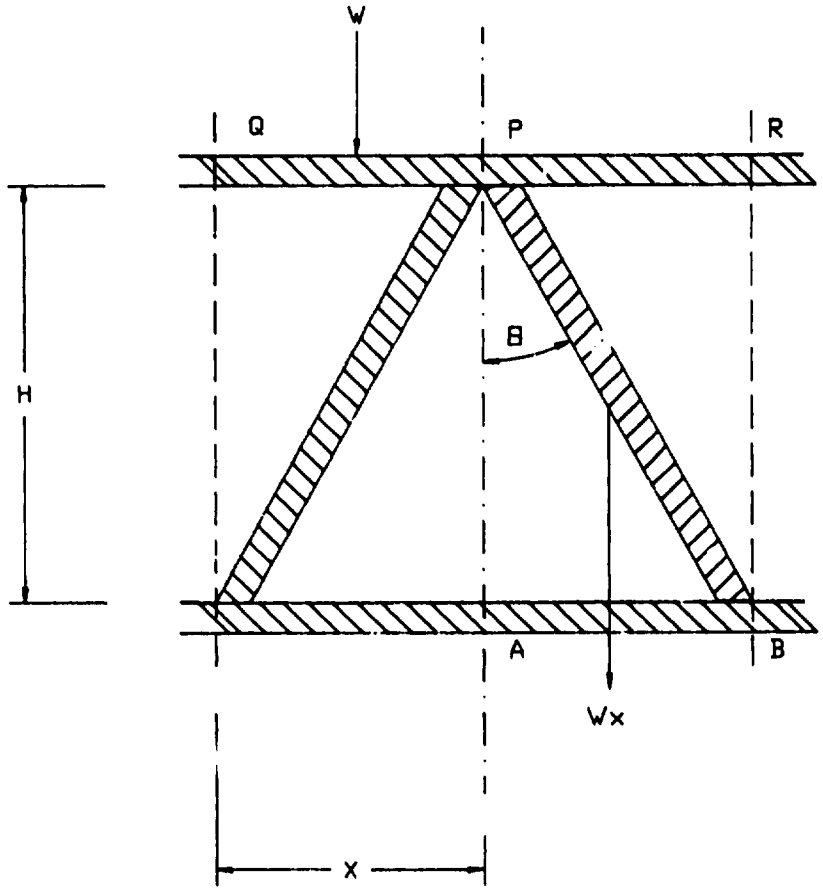

FIG. A1 SECTION THROUGH SANDWICH BEAM

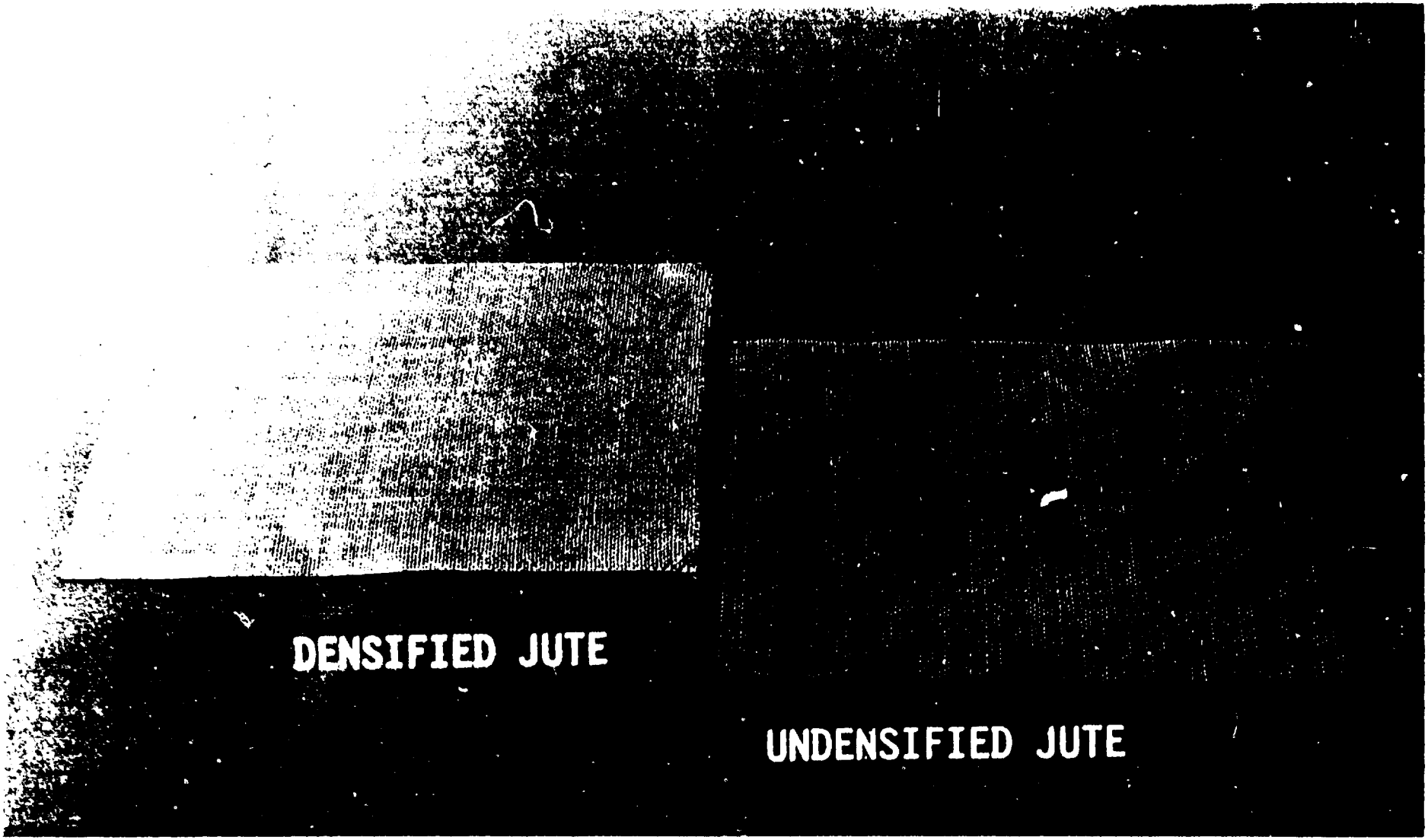

FIG. 1. DENSIFIED AND UNDENSIFIED JUTE CLOTH

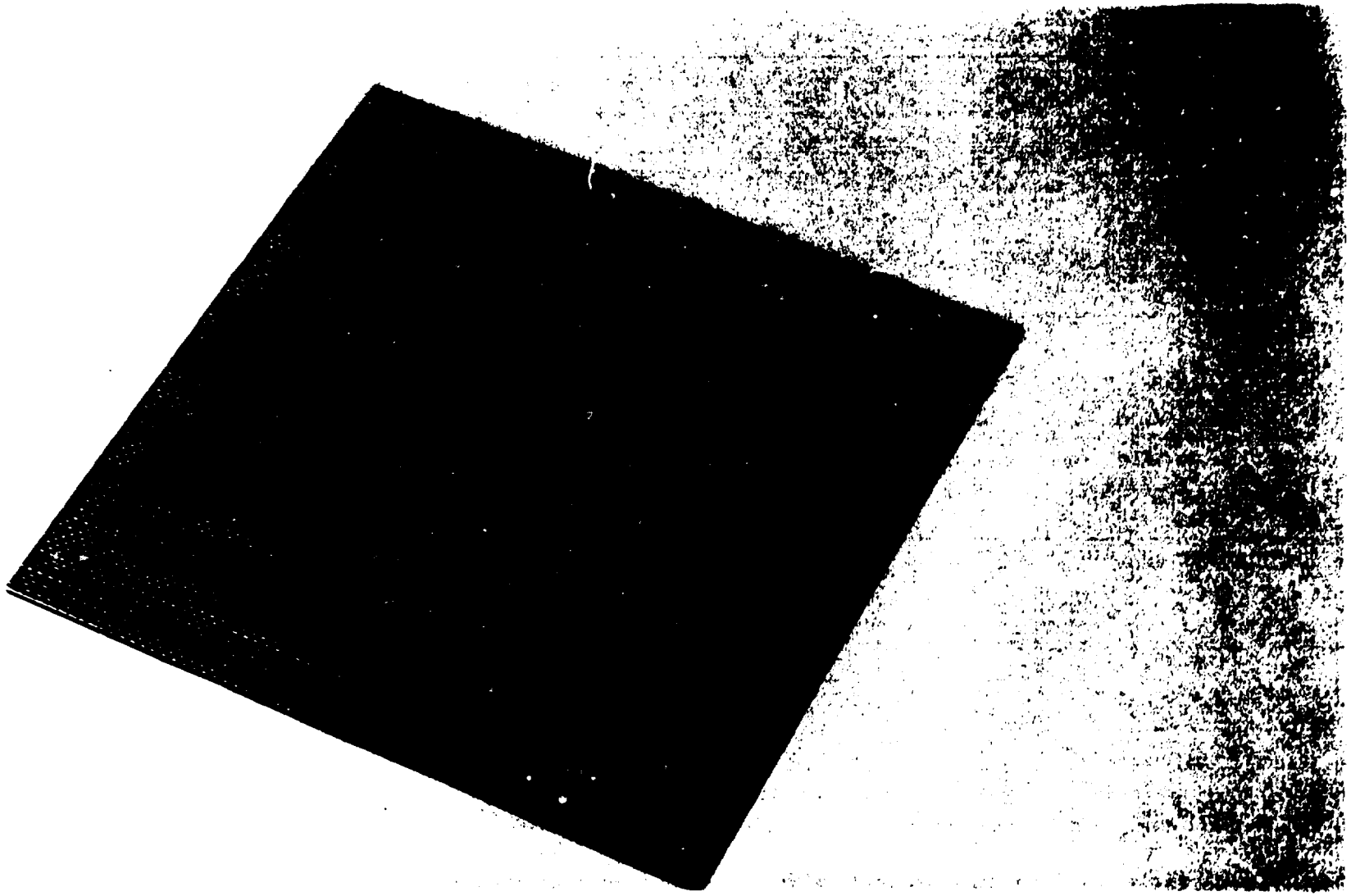

FIG. 2. JUTE PHENOLIC SHEET

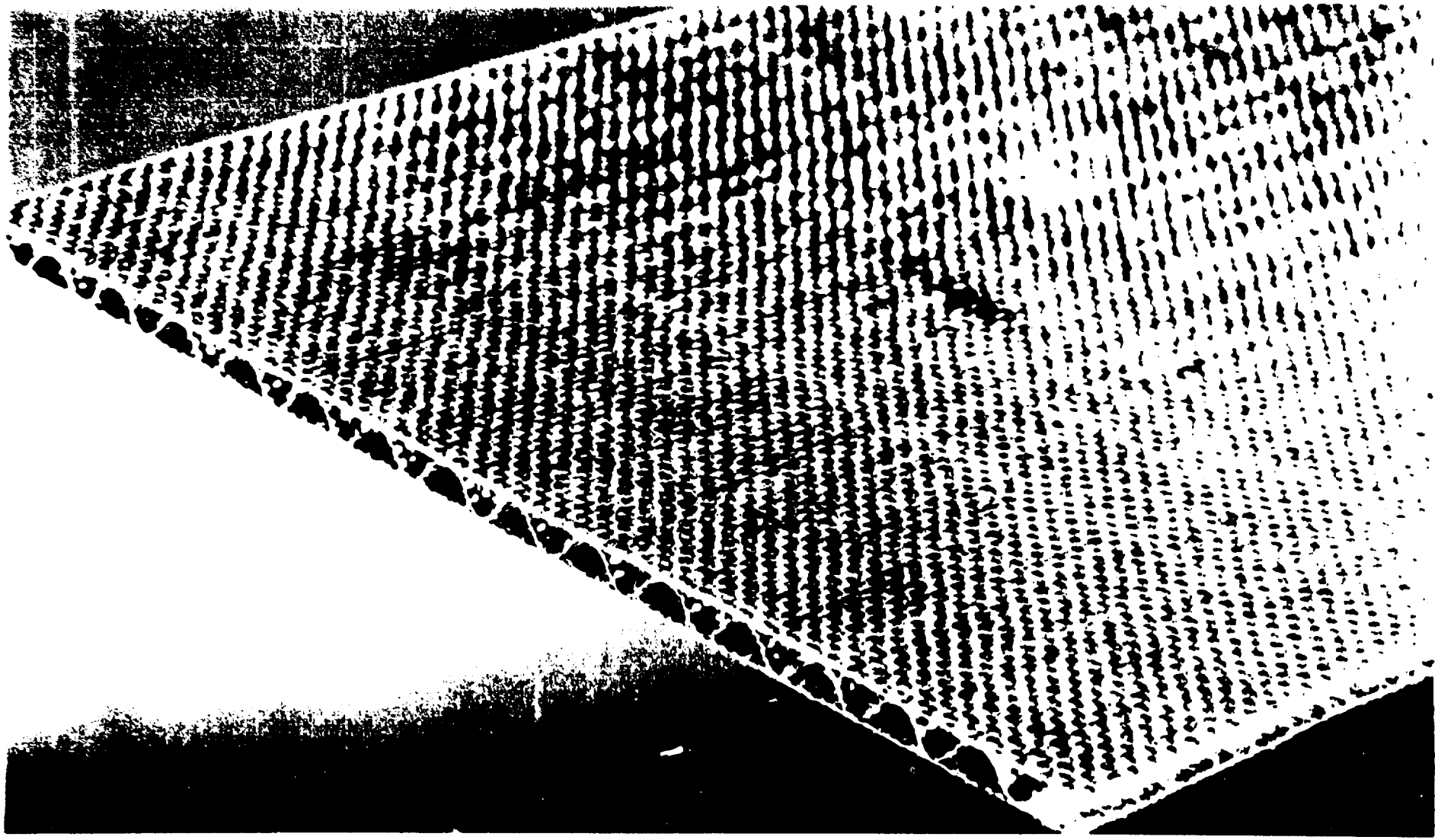

FIG. 3. CORRUGATED POLYETHYLENE JUTE SANDWICH PANEL

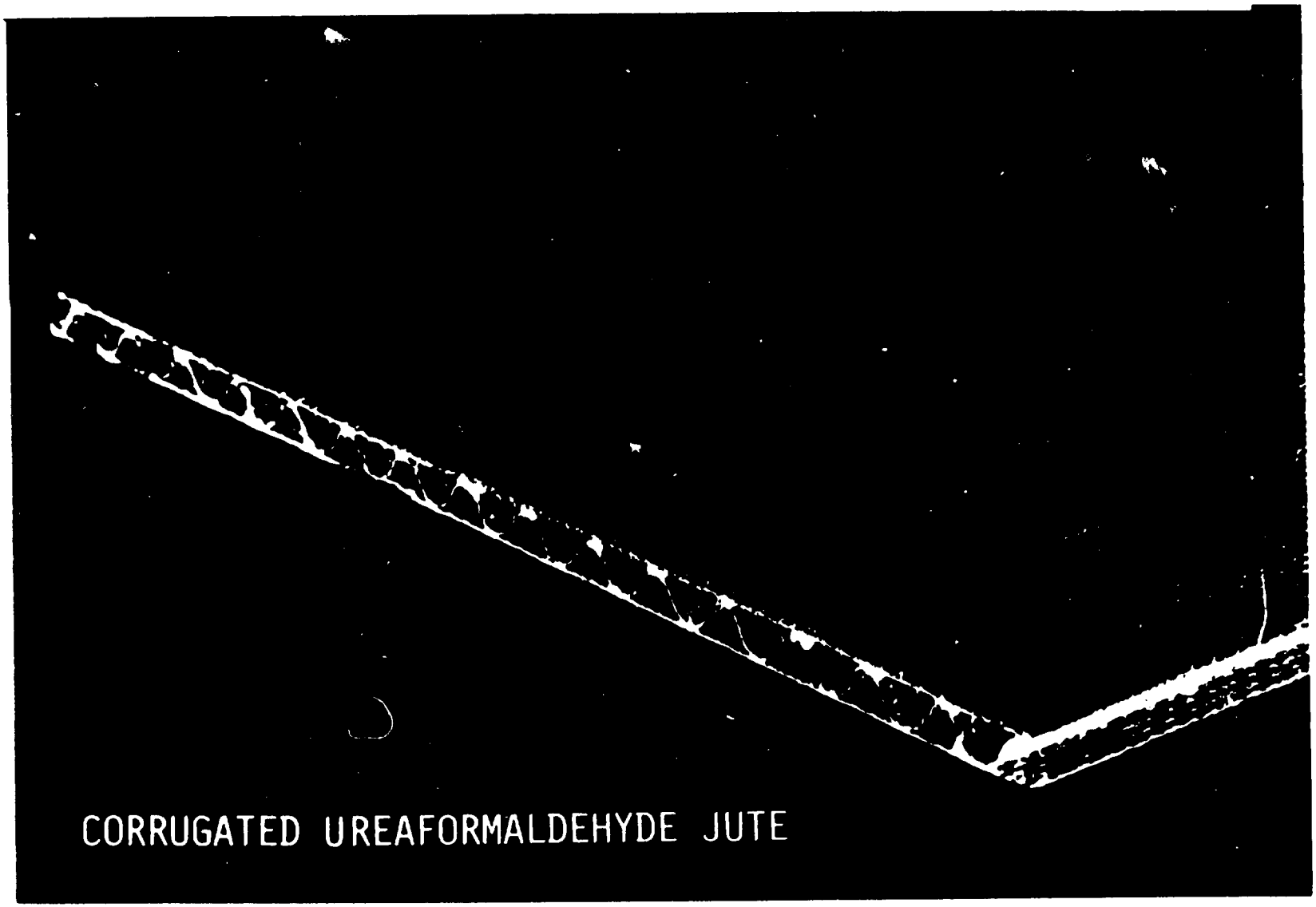

FIG. 4. CORRUGATED UREA FORMALDEHYDE JUTE SANDWICH PANEL

FIG. 5. JUTE/J1041H PHENOLIC COMPOSITE, NON-DENSIFIED, x40

FIG. 6. JUTE/J1041H PHENOLIC COMPOSITE, DENSIFIED, x40

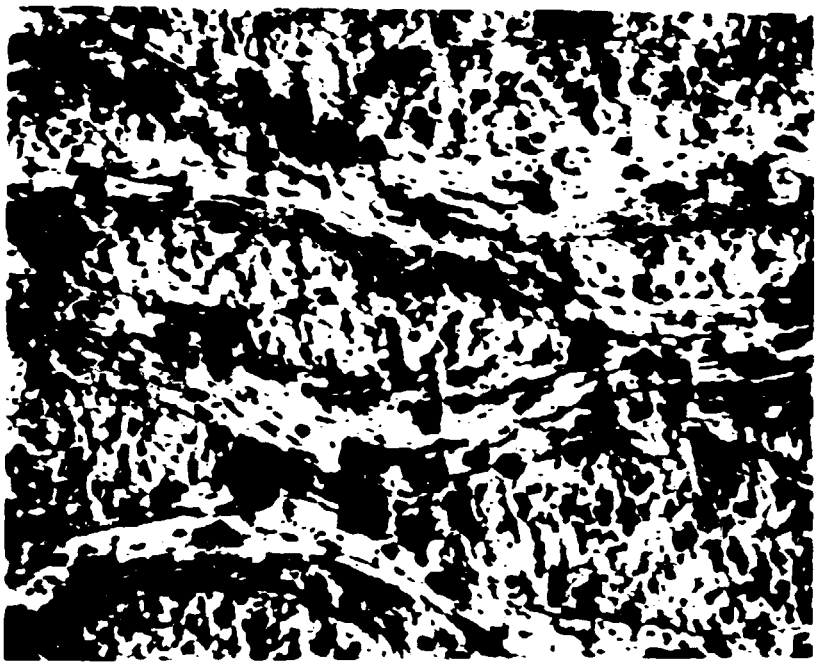

FIG. 7. JUTE/W436 UREA FORMALDEHYDE COMPOSITE, DENSIFIED, OVEN DRIED, x40

FIG. 8. JUTE/W436 UREA FORMALDEHYDE COMPOSITE, DENSIFIED, AIR DRIED, x40

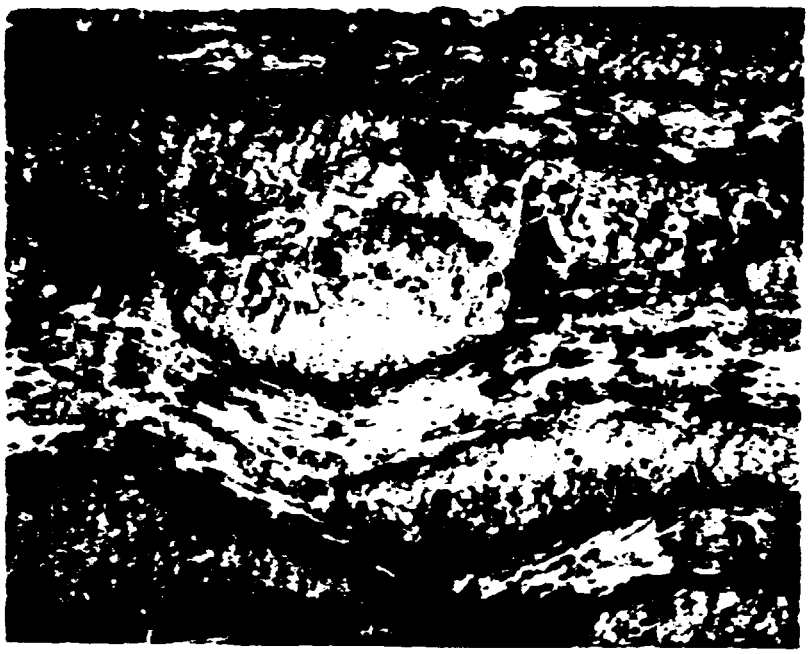

FIG. 9. JUTE/BL434 MELAMINE COMPOSITE, DENSIFIED, OVEN DRIED, x40

FIG. 10. JUTE/POLYETHYLENE COMPOSITE, DENSIFIED, x40

FIG. 11. JUTE/POLYPROPYLENE COMPOSITE, DENSIFIED, x40

FIG. 12. MODEL JUTE/POLYETHYLENE BOXES