Expanded polystyrene composite door shutters —an alternative to wooden door shutters

K. K. Asthana*, Rajni Lakhani and L. K. Aggarwal

Organic Building Materials Division, Central Building Research Institute, Roorkee – 247 667, India

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The paper describes in brief the work carried out for the development of expanded polystryrene (EPS) composite door shutters which can be used as an alternative to wooden door shutters. The door shutters have been developed by using EPS sheet as core material and medium density fibre (MDF) board—a product based on agricultural waste and/or agro-forestry plants—as facing and framing material. An interpolymer adhesive based on cashew nut shell liquid and polyurethane resin has been developed for bonding the core material with the core frame and facing material. The properties of the adhesive, the physico-mechanical properties of the EPS composite and the properties and field trial results of the developed door shutters are discussed. EPS door shutters are found to have properties comparable to wooden door shutters and therefore this new material will be useful for the building industry.

Keywords: shutters; composites; expanded polystyrene

Wood is one of the oldest materials used by man for several construction and industrial purposes. Due to the unique natural properties of wood, its use is increasing with time. Forests, which are the main source of wood, are disappearing at an alarming rate adding to an ecological imbalance. According to the estimate of the National Commission on Agriculture, the demand for industrial wood in India will be between 47.0 million m^3 (low growth) to 65.5 million m^3 by the year 2000. Local availability of wood from Indian forests is estimated to be 45.0 million m^3 by the year 2000, leaving a gap of 10.5 million m^3. This critical situation encourages a search for the development of materials which can be used as alternatives to wood-based products.

Doors and window shutters are some of the essential requirements of a building which consumes 60–70% of the total wood consumed in the building. With this background in view, the present work on the development of sandwich type composites and door shutters which can be used as wood substitutes has been undertaken. The studies resulted in the development of EPS composite doors and panelling products. In this paper studies carried out on the above mentioned development work are summarised.

Sandwich composite

The sandwich composites are a special form of laminated composite in which thin, strong, stiff, hard but relatively heavy facings are combined with thick, soft, light and weaker cores to provide lightweight composites. The composites thus obtained are stronger and stiffer in many respects than the individual components. Sandwich panels with a foam core have shown greater promise in construction activity and have helped architects and engineers the world over to develop new design techniques[1–3].

Experimental

The main constituent of sandwich type EPS composite panelling products are core material, facing and framing material and adhesive.

Core material

The rigidity, thermal and sound insulation characteristics of the composite depend upon the core material. In this study expanded polystryrene (EPS) sheet has been used as core material. The EPS sheet used was of self-extinguishing type and conformed to the requirements specified in IS:4671–1984[4].

Facing and framing material

In order to achieve 100% wood substitute products, efforts have been made to use facing and framing materials based on agro-forest or agricultural wastes. In this paper, work carried out by using medium density fibre (MDF) board—a product based on agricultural waste and/or agro-forestry plants—as facing and framing material is discussed. Water absorption, dimensional

* Correspondence to Dr K. K. Asthana

Rlakhani

stability and cohesive strength of the MDF board were determined as per IS: 12406–1988[5]. On the basis of the results obtained from various tests, it has been observed that the properties of the MDF boards commercially available in India change in high humidity conditions. Fungal attack was also observed on a few boards kept in store under normal conditions. Therefore to improve the properties of the facing and framing materials these were treated with polymeric material.

Adhesive

The adhesive used in this study was prepared by modifying the indigenously available phenolic resin from renewable resources by polyurethane resin. The modified adhesive shows an appreciable improvement in its properties, especially water resistance and bond strength which are essential for the production of composite panels.

The developed adhesive was tested for adhesive strength as per the procedure mentioned in IS: 848–1974[6]. Specimens were prepared by using 25 × 125 mm size strips of MDF sheets and the two strips were bonded to form a lap joint by applying adhesive on a 25 × 25 mm area and the specimens thus prepared were subjected to different curing conditions. Shear strength and bond strength at different curing intervals were determined.

Development of EPS composite panels

After characterizing the raw materials, sandwich composite panels were prepared by using treated MDF boards as facing material and self extinguishing type EPS sheet as core material using the developed adhesive as binding material. EPS composite thus prepared is shown in *Figure 1*.

The composite samples thus obtained were tested for various physico-mechanical properties following the procedure given in IS:2380-1977[7]. Thermal conductivity and sound transmission loss were determined as per IS:3346–1980[8] and ASTM E 90–1975[9] respectively. Fire properties of the composite were also determined as per BS:476 Part 5–7[10] and ASTM E 662–1979[11] specifications.

Development of EPS composite door shutters

The details of the core frame required to hold the core and facing material in proper shape are given in *Figure 2*. The core material, i.e. EPS sheet, along with blocks of required sizes were then fixed in the core frame. The blocks were used for fixing the fixtures and fittings in the door shutter. The facing material was then bonded with the core frame using the developed adhesive under pressure. The door shutters were then cured for 6–7 days and trimmed. A coat of primer was applied on both sides of the door shutter. The developed door shutter is similar in appearance to traditional flush door type shutters as shown in *Figure 3*.

To assess the suitability of these door shutters, they

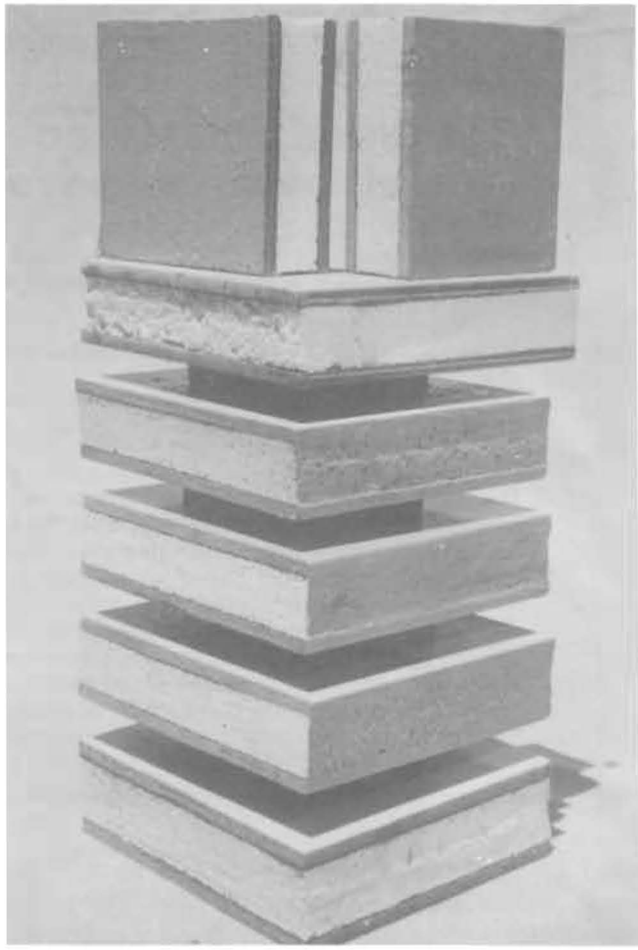

Figure 1 EPS composite

were tested as per IS4020–1994[12]. The specification is for the acceptability criteria for wooden door shutters. Therefore, if the newly developed door shutters satisfy these criteria, they can be used as an alternative to wooden door shutters in residential buildings.

Test methods for door shutters

End immersion test

The door shutter was immersed to a height of 300 mm in water at ambient temperature for 24 h and then allowed to dry for 24 h at ambient temperature. The cycle was repeated eight times. There should be no delamination at the end of the test.

Varying humidity tests

This test is intended to give quality assessment of the resistance of the door towards different weather conditions of changing humidity and the consequent moisture content at various portions of the door. The door was placed in the conditioning chamber at a temperature of 27±2°C, and humidity was maintained at 40% for one week. The length, breadth, thickness and diagonal of the door were noted at the end of the week. Then, the humidity was raised to 90% and the door remained again for one week. The changes in the above dimensions were measured. After this the humidity was reduced back to 40% for one week. The dimensions

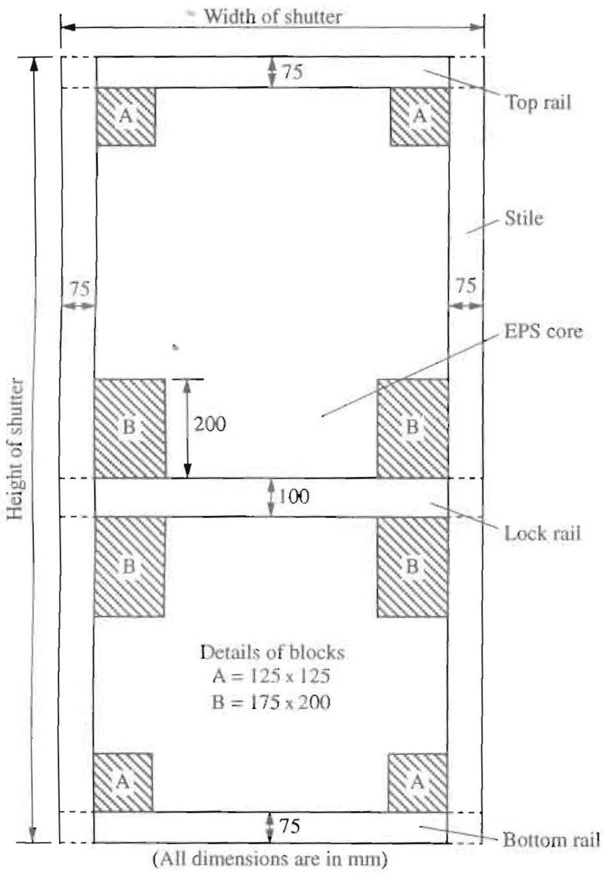

Figure 2 Details of core frame and blocks

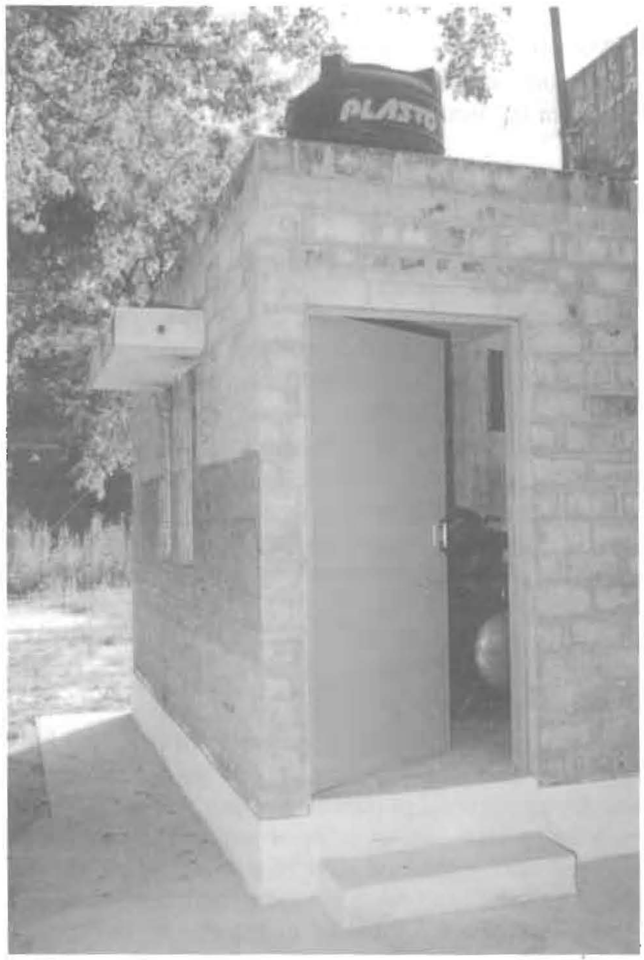

Figure 3 EPS door shutter

were measured again after the end of the period and the extent of return to the original sizes was calculated. The general condition of warping and delamination, if any, was noted. General planeness of the door was checked with the help of the rigid flat across the diagonal line and the maximum gap was measured up to the second decimal place of a millimetre. There should not be any visible warping, twisting or delamination and where precision is required the maximum departure from the general planeness should not be more than 1.0 mm. The maximum increase in size at the high humidity (RH = 90%) should not be more than 0.5% and the recovery to the original size of the door at the lower humidity (RH = 40%) should be at least 90%.

Differential humidity test

The conditioning box was prepared so that the humidity inside was different from the external humidity by about 40%. The door was kept in such a way that one of its faces was exposed to the humidity in the box and the other was exposed to the room atmosphere. After the end of a week, the general condition of the door, that is, warping or twisting if any, was recorded. The maximum departure of the dry side from the original plane of the door was measured by means of a dial gauge, correct to the second decimal place of a millimetre. The door was then allowed to recover from differential moisture on the two faces for about a week, and the extent of recovery was noted. There should be no visible warping or twisting after recovery. Maximum departure of the dry side to the original plane should not be more than 3.0 mm. There should be at least 90% of recovery of the dry side to the original plane in one week after the removal of differential moisture content.

Slamming test

The door was placed in a horizontal position suitably hinged at three equidistant places on one of the long edges. The other edge was lifted up so as to form an angle of 30° at the hinged edge and allowed to drop under its own weight several times on the wooden rail. The general condition was noted after every ten drops. There should be no visible damage caused in any part of the door by the first 50 drops.

Impact indentation test (dynamic punching test)

The door was placed horizontally resting equally on all four edges. A steel ball, 500±10 g in weight, was allowed to fall freely from a height of 750 mm at 10 randomly selected different points on the surface of the door avoiding proximity to the edges. If any indentation was noticed the depth was measured by the dial gauge and recorded. The general behaviour of the door and delamination if any was also noted. On dropping the steel ball at any point there should be no abnormal defects, such as cracking, tearing or delamination and indentation more than 0.2 mm.

Shock resistance test

The door was supported in a vertical plane flush with a fixed frame. A rope with a leather ball, 200 mm in diameter and containing 50 N sand, was tied on the central vertical line just above the door. The length of the rope was such that the ball strikes the door at a point 200 mm above the bottom end on the vertical central line of the door. The ball was pulled away from the door to a height of 1.25 m from the plane of the striking place and allowed to strike the door several times in quick succession. The general condition was noted after every five blows. The test was repeated with the door turned upside down in the vertical plane. There should be no visible damage in any part of the door after the first 15 blows on each end.

Edge loading test

The door was hung vertically, pivot-supported on a longitudinal edge and loads were applied on the top of the other longitudinal edge parallel to the plane of the door. The loading was done in steps of not more than 100 N at a time until a load of 1000 N was reached and kept constant at the load for a period of half an hour. The defections at the loaded edge at the end of the period were recorded. The deflection was also measured immediately on removal of the load. On removal of the load there should not be a residual deflection of more than 0.5 mm, failing which the test may be repeated on the other edge in the reverse direction. The deflection of the edge at the maximum load should not be more than 5 mm.

Screw holding power test

Six prebores of 3 mm diameter were made at regular intervals on the face of the door along the stiles/rails of door frame as well as on the edges of the door shutter. Screws of 8 SWG size and 50 mm length were fixed at these points to a depth of 3 cm. The door was then placed at the testing machine and load was applied at the rate of 2 mm min^{-1} for withdrawal of one screw at a time. The maximum load required for complete withdraw was noted in each case. The maximum and minimum values were recorded. The required load to withdraw the screw completely should not be so low as to hamper the fixation of any external attachment to the door by means of screws. A minimum of 1000 N is recommended for guidance. On withdrawal, there should be no visible damage to the surface either by delamination or extra chipping at the points of withdrawal.

Local planeness test

The door was placed in a horizontal position and a square of 200 mm made on the face of the door. The dial gauge was placed on each cross point of the squares. The depth of the point at each cross point of the squares was measured with reference to the planeness of the surrounding surface. The ratio of the depth to the distance between corresponding corner points was measured and the maximum was recorded. The depth of depression at any point should not be more than 0.5 mm.

Resistance to buckling test

The door shutter was hinged to a rigid vertical frame in a way similar to actual installation. The shutter was opened to 90° and secured at its top free corner to prevent any lateral movement but remaining free to move vertically. A load of 400 N was applied on the handle at right angles to the plane of the shutter and in the direction of opening in increments of 100 N, each new increase of load being applied only after stabilization of the deformation created by the previous loading. The deformations at the lower free corner were measured both during loading and after unloading. The shutter should not show any deterioration and any residual deformation should not be more than 5 mm after 15 mm of unloading. The initial deflection under a load of 400 N should not be more than 50 mm.

Results and discussion

The results of improvement in the properties of the treated boards in comparison to untreated boards are shown in *Table 1*. It is apparent that the treated boards show significant improvement in dimensional stability and water absorption at room temperature as well as at a higher temperature, i.e. 70°C. Moreover, no fungal attack was observed on the MDF boards kept at normal laboratory conditions.

The results of rate of development of strength of the developed adhesive under various curing conditions are given in *Table 2*. The rate of development of bond strength as well as shear strength of polyurethane modified adhesive is much faster in comparison to unmodified adhesive. The bond strength of the modified adhesive after 3 days of room temperature curing is higher than the strength of unmodified adhesive even after 15 days of curing. The reduction in bond strength in high humidity conditions is much higher in the case of unmodified adhesive in comparison to modified adhesive (*Table 2*) indicating that the unmodified adhesive is not suitable for the preparation of composite material as it may not exhibit good long-term durability. The results of adhesive shear strength are also similar to the results of bond strength as discussed above.

The results of physico-mechanical properties and fire resistance of the developed composite material are given in *Tables 3* and *4*, respectively. Density, water absorption and thickness swelling of the composite material are comparable with that of wood, while thermal conductivity is better in comparison to that of wood. The fire resistance properties of EPS composites are also comparable with that of wood (*Table 4*).

Table 1 Comparison of untreated and treated MDF board

Properties	MDF (interior grade) Untreated	Treated	MDF (exterior grade) Untreated	Treated
At room temperature				
Water absorption (%)	48.49	13.53	26.59	3.40
Change in length (%)	0.72	0.52	0.81	0.32
Change in width (%)	0.68	0.52	0.81	0.32
Change in thickness (%)	88.80	11.72	12.38	11.69
At 70°C				
Water absorption (%)	78.68	57.07	54.38	29.68
Change in length (%)	Spoiled	0.64	0.92	0.75
Change in width (%)	Spoiled	0.62	0.94	0.69
Change in thickness (%)	Spoiled	68.00	29.70	15.00

Note: All data are based on 24 h immersion in water.

Table 2 Strength developments at different curing conditions

Curing conditions	Bond strength ⊥ to surface (N/mm^2)		Adhesive shear strength (N/mm^2)	
	PU modified	Unmodified	PU modified	Unmodified
Room temperature				
3 days	2.0[a]	0.5	2.45[a]	0.62
15 days	2.0[a]	0.8	2.50[a]	1.50
24 h at 90°C	2.0[a]	1.8[a]	2.50[a]	2.40[a]
Cured for 3 days at RT followed by:				
7 days at 100% RH	1.80[a]	0.5	2.40[a]	0.64
15 days at 100% RH	1.52[a]	0.6	2.30[a]	0.50
30 days at 100% RH	1.36[a]	0.4	2.16[a]	0.50

[a] Bond remains intact but samples failed
RH: Relative humidity

Table 3 Properties of EPS composite

Properties	Results
1 Density (g/cc)	0.30–0.31
2 Water absorption (%) 24 h	6.60–7.30
3 Thickness swelling (%) 24 h	1.02–1.40
4 Thermal conductivity (kcal/h °C)	0.052–0.054
5 Sound transmission loss (25 mm dB)	35.00–40.00
6 Tensile strength ⊥ to surface (N/mm^2)	0.20–0.30
7 Modulus of rupture (N/mm^2)	6.00–6.40
8 Modulus of elasticity (N/mm^2)	118–126
9 Stress at proportional limits (N/mm^2)	2.70–2.95

Table 4 Fire properties of EPS composites

Test	Observations EPS	Kail wood
Ignitability	P	P
Fire propagation index,		
i	7	16
I	25	41
Surface spread of flame classification, Class	2	4
Maximum specific optical density (D_m)		
Non-flaming	736	228
Flaming	649	327

P: Not easily ignitable

The results of various tests carried out on the developed EPS door shutters are given in *Table 5*. The EPS door shutter fulfils the minimum requirements laid down in IS: 4020–1994, Door shutters–Methods of tests. Therefore on the basis of these observations, it can be concluded that the developed door shutters should behave similar to wooden door shutters in actual use. However, there is a need to generate long-term performance data by carrying out accelerated laboratory tests as well as their performance in actual use conditions. Work in this direction is in progress. To generate data on the long-term performance of EPS door shutters in actual use conditions, some doors have been installed at various locations. It has been observed that there has been no visual failure in the door shutters installed for the last 2 years. One of the door shutters installed about 2 years ago is shown in *Figure 3*.

Table 5 Test results of EPS door shutters

Name of test	Observations
1 End immersion	No delamination
2 Varying humidity	No abnormal defect Maximum departure along diagonals—0.80 mm Recovery—100%
3 Differential humidity	No abnormal defect Maximum departure along diagonals—1.35 mm Recovery—82%
4 Slamming	No visible damage
5 Impact indentation	No abnormal defect Maximum indentation—0.01 mm
6 Shock resistance	No visible damage
7 Resistance to buckling	Deflection at free corner at 400 N load—80 mm Residual deflection at free corner—10 mm
8 Edge loading	Deflection at 1000 N load—1.55 mm Residual deflection—0.43 mm
9 Screw holding power, N	
Edge	1450–1600
Face	2000–2500
10 Local planeness	Values varying up to 0.05 mm

Conclusions

1 The developed EPS composite material can be used for partitioning, panelling and cladding purposes as well as for table tops and cupboards, etc.

2 Door shutters using this composite material have also been developed. These fulfil the requirements laid down in IS:4020–1994 and, therefore, can be used in place of traditional wooden door shutters.

3 On the basis of the results obtained from various laboratory tests and field trial studies, it can be concluded that EPS door shutters are expected to have long-term performance comparable with wooden doors.

4 EPS door shutters are 100% wood substitute, lightweight, have excellent sound and thermal insulation, can be polished and painted, are easy to install, and economical compared to wooden door shutters.

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