Steam Stabilization of Jute-based Composites

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ABSTRACT

Many techniques have been used over the years to dimensionally stabilize jute fiber against the swelling forces imparted when the fiber is compressed during composite formation (irreversible swelling) and when the fiber sorbs moisture (reversible swelling). When jute fibers are pressed into a fiberboard, the fibers are compressed and flattened. Because of the structure of the cell wall, the compressed fiber has a "memory" of its original configuration even though it now exists as a deformed fiber. When the compressed fibers sorb moisture, not only does reversible swelling take place, but the compressive forces imparting in the board upon pressing are relieved due to recover?, of the original configuration through cell wall memory.

The imparted compression stresses can be reduced if the matrix is plasticized by steaming during pressing so that the fiber takes on a new flattened shape without the old memory. This can be done using contained steam in the hot press during and after pressing. After pressing four minutes at 200°C under steam pressure, jute fiberboards show less than 10 percent thickness swelling after two hour water soak as compared to over 40 percent for non-steamed boards. These boards did not contain any added adhesive. The stabilized boards were re-fiberized, a phenolic resin added, formed into a mat. and pressed into boards again. Swelling in water of the phenolic bonded boards was about the same as boards with no adhesive but strength properties are improved with the use of the adhesive.

Swelling of jute fiber

Jute and other lignocellulosic resources change dimensions with changing moisture content because the cell wall polymers contain hydroxyl and other oxygen-containing groups that attract moisture through hydrogen bonding [Stamm 1964, Rowell and Banks 1985]. The hemicelluloses are mainly responsible for moisture sorption, but the accessible cellulose, noncrystalline cellulose, lignin, and surface of crystalline cellulose also play major roles. Moisture swells the cell wall, and the jute fiber expands until the cell wall is saturated with water (fiber saturation point, FSP). Beyond this saturation point, moisture exists as free water in the void structure and does not contribute to further expansion. This process is reversible, and the jute fiber shrinks as it loses moisture below the FSP. This process is called reversible swelling.

When jute fibers are compressed into a fiberboard, the fibers are compressed and flattened. Because of the structure of the cell wall, the compressed fiber has a "memory" of its original configuration even though it now exists as a deformed fiber. When the compressed fibers sorb moisture, not only does reversible swelling take place as described above, but the compressive forces imparted to the board upon pressing are relieved due to recovery of the original configuration through the memory. This process is called irreversible swelling. The major thickness swelling of the board is due to irreversible swelling. Normally irreversible swelling is significantly higher than reversible swelling for densified fiberboard if no preventive measure is employed. Effective solution of reducing swelling of jute fiberboard should prevent the build up of internal stress within the board, relieve internal stress in the board prior to use, and prevent adsorption and absorption of moisture.

If the internal stresses that were imparted on the compressed fiber during pressing could be reduced, the irreversible swelling could be reduced. One way to do this is to plasticize the cell wall matrix by steaming during compression so that the fiber takes on a new shape without the old memory. In this way the compressive forces have been relieved and the matrix modified fiber now only undergoes reversible swelling upon contact with moisture.

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The procedure being tested in these experiments differs from earlier heat and steam treatments of wood [see for example Stamm 1937, Seborg et al 1945, Stamm et al 1946, Seborg et al 1953, Burmester 1973, Giebeler 1983, Hillis 1984, and Hsu 1988] where the wood or fiber is steamed without containment of the steam. In the present research steaming is done not only before pressing but also during pressing and the hot compressed fiber is cooled under compression. This has been done using both solid wood [Inoue et al 1992, 1993] and wood fiber [Rowell et al 1995].

The research described in this paper was done in two parts. Part 1 was a proof of concept phase where different pressing temperatures, pressing times, and different board densities were tested. Thickness swelling at two different water soaking times were used to evaluate the experimental parameters. In part 2 boards were made in the steam system and tested without using any adhesive or using 7% phenol-formaldehyde resin.

The pressing system used in this research is shown in **Figure 1.** Initial studies were done using a O-ring seal. This was later changed to a flat silicone ring which was 5 cm on each side with a 25 cm center cut out.

Part 1 - experimental

In preliminary experiments, raw jute bast fiber of Tossa *(Corchorus Olitorious)* Quality TD 7 grade was dried overnight at 105° C. A water spray was used to bring the fiber moisture content to 15%. The fiber was then hand formed into a mat and the mat was placed in the pressing ring. Two densities of boards were made at three different temperatures for four different pressing times using jute fiber. The two board densities were 750 kg/m^3 and 1000 kg/cm^3, the pressing temperatures were 150, 175 and 200°C, and the times for pressing were 1, 5, 10 and 15 minutes.

Water-soaking tests

Ovendried, thickness measured specimens (50 X 50 mm) were taken through one of two soaking tests: Test 1 - Specimens were soaked for 2 hr in water at room temperature, or Test 11 - Specimens were soaked for 24 hr in water at room temperature. At the end of each soaking cycle, wet specimens were placed on a flatbed micrometer and the increase in thickness as compared to its oven dry thickness determined. Three specimens were tested and the results averaged.

Results

Because of the limited number of specimens per individual test, statistical analysis of the data was not appropriate. The results presented here should be considered as indicative of trends that a larger, statistically valid experiment should confirm.

Table 1

Increase in thickness swelling of jute boards made with fiber pressed at 150°C for varying lengths of time. (Board density 750 kg/M^3)

Pressing Time	Thickness Swelling at	
Min	2 Hrs	24 Hrs
	←—— % ——→	
1	87	105
5	48	55
10	37	46
15	28	42

Table 2

Increase in thickness swelling of jute boards made with fiber pressed at 175° C for varying lengths of time. (Board density 750 kg/m^3)

Pressing Time Min	Thickness Swelling at 2 Hrs	Thickness Swelling at 24 Hrs
	← %	% →
1	62	74
5	27	31
10	18	18
15	16	16

Table 3

Increase in thickness swelling of jute boards made with fiber pressed at 200° C for varying lengths of time. (Board density 750 kg/m^3)

Pressing Time Min	Thickness Swelling at 2 Hrs	Thickness Swelling at 24 Hrs
	← %	% →
1	50	62
5	16	16
10	8	9
15	5	7

Table 4

Increase in thickness swelling of jute boards made with fiber pressed at 150° C for varying lengths of time. (Board density 1000 kg/m^3)

Pressing Time Min	Thickness Swelling at 2 Hrs	Thickness Swelling at 24 Hrs
	← %	% →
1	127	162
5	62	73
10	50	55
15	41	45

Table 5

Increase in thickness swelling of jute boards made with fiber pressed at l75°C for varying lengths of time (Board density 1000 kg/M^3).

Pressing Time	Thickness Swelling at	
Min	2 Hrs	24 Hrs
	← % →	
1	71	82
5	33	42
10	27	27
15	22	24

Table 6

Increase in thickness swelling of jute boards made with fiber pressed at 200° C for varying lengths of time. (Board density 1000 kg/m^3)

Pressing Time	Thickness Swelling at	
Min	2 Hrs	24 Hrs
	← % →	
1	50	55
5	21	21
10	7	10
15	4	6

Discussion and conclusions

The results from these first experiments showed that pressing for less than 5 minutes was too short a time to result in steam stabilization. Thermocouples placed in the fiber mats showed that the desired temperature was not reached in the short pressing time. A minimum time of $1^1/_2$ to 2 minutes is required to bring the fiber mat temperature up to the desired level

Results at 5 min pressing time show that stabilization was achieved but was not nearly as effective as steaming at 10 min at each temperature. Pressing longer than 10 min did not significantly decrease thickness swelling in liquid water.

Pressing at 150°C at all pressing times for both board densities, produced boards with very high levels of thickness swelling (28-162%) after 2 hrs and 24 hrs. Pressing at 175°C at pressing times at or greater than 5 minutes for both board densities, produced boards with greatly improved thickness swelling (16-42%) after 2 hrs and 24 hrs. Pressing at 200°C at pressing times at or greater than 5 minutes for both board densities, produce boards with very low levels of thickness swelling (4-21 %) after 2 hrs and 24 hrs.

The results of Part 1 research showed that the boards with the lowest thickness swelling were produced using a pressing temperature of 200°C, and a pressing time of 10-15 minutes for both board densities.

Part 2 - experimental

Raw jute fibers of Tossa *(Corchorus Olitorious).* Quality TD 7 grade were chopped through straw chopper (see Figure) The chopped fibers were then passed through hammer mill lo get fibers of approximate length of 3/8".

Water was sprayed on the fiber to increase the moisture content to 15% on dry weight basis. The fiber was then hand formed into a mat of 20 X 20 cm and the mat was placed in the pressing mold (30 x 30 cm, see Figure 10). The mold/mat was placed in a hydraulic press heated to 200°C. The press was closed and held at 250 psi pressure for either 4 or 8 minutes. The target sp. gr. of all the boards was 0.7.

Resin application and board fabrication using resin

For boards to be formed using a phenolic resin, the steam stabilized board described above was run through a Bouer refiner (see Figure 2) to re-fiberize. Phenol-fomraldehyde resin was sprayed through laboratory blender on either untreated milled jute fiber or steam stabilized jute fiber. Final resin level of 7% was used based on oven dry weight of fiber.

Three types of boards were produced with resin: a) Steam stabilized jute fibers steamed for 4 minutes treatment time with 7% resin, b) Steam stabilized jute fibers steamed for 8 minutes treatment time with 7% resin. and c) Untreated jute fibers with 7% resin as control. The target sp. gr. of all the boards was 0.7.

Water sorption and thickness swelling tests

Specimens were tested in Test 1 - 24 hr. water soaking at room temperature, Test II - 2 hr. boiling water test., or, Test III - wetting/drying cycles that consisted of i) 24 hours water soaking at room temperature, ii) 24 hours drying at 60°C, iii) 2 hours in boiling water, iv) 24 hours drying at 60°C. At the end of each soaking cycle, wet specimens were weighed and then placed on a flatbed micrometer and the increase in thickness as compared to its original oven dry thickness determined. At the end of each dry cycle, specimens were also placed on a flatbed micrometer and the increase in thickness as compared to its original oven dry thickness determined.

Strength tests

Two point static bending tests were conducted on board specimens as per ASTM 790M using 160 mm span and a head speed of 4.3 mm/minute to determine modulus of rupture (MOR) and modulus of elasticity (MOE).

Equilibrium moisture content

The boards were cut into 50 x 50 mm specimens and dried at 105°C. After oven drying, weights and thicknesses were taken. All specimens were then placed in the 65% relative humidity conditioning room (20°C) until the specimens reached equilibrium and reweighed. Equilibrium moisture content (EMC) was determined based on oven dry specimen weight.

Results and discussion

Figure 2 shows the water sorption and thickness swelling tier 24 hours water soaking of control samples with no adhesive and boards made at 4 and 8 minutes steaming time with and without resin. The results show that the addition of resin does result in a small decrease in thickness swelling as compared to boards with no adhesive. A maximum reduction in water sorption and thickness swelling was achieved at 8 minutes pressing time without resin.

Figure 3 shows the results of water sorption and thickness swelling after the 2 hour boil test. The results are similar to those found in the 24 hour soak test. The boards made using no resin showed the better results in both the water sorption and thickness swelling tests as compared to boards made with resin

Figure 4 shows the results of the cyclic water/drying test on thickness swelling. Boards made using 8 minutes of steam pressing gave the best results. The control board results shown in Figure 4 show very clearly the large irreversible swelling that exists in boards that have not been stabilized using steam

Figure 5 shows the results of the cyclic water/drying test on water sorption. Boards made using the phenolic resin show the lowest water sorption during the wet parts of the cycles. There is little difference in water sorption in boards with or without resin during the dry parts of the cycles.

Figures 6 and 7 shows the results of strength tests. A slight increase in MOE is seen in boards using resin as compared to boards without resin. MOE is highest (Figure 6) for boards prepared at 4 minutes steam pressing as compared to 8 minutes steam pressing time. This may be due to fiber degradation that may take place at the longer pressing time. MOR results (Figure 7) show a big difference between boards with and without resin. Boards made using resin are more than twice as strong as boards made without resin.

Finally, Figure 8 shows the equilibrium moisture content of all boards. The initial EMC for the control boards was 8.8%. Steaming results in a lowering of the EMC in all boards with or without resin to a value of approximately 5%.

Conclusions

Steam stabilization of jute shows a marked improvement in both water sorption and thickness swelling. There is a marginal improvement in the use of phenolic resin in water sorption.. thickness swelling and MOE. There is a great improvement in MOR using phenolic resin.

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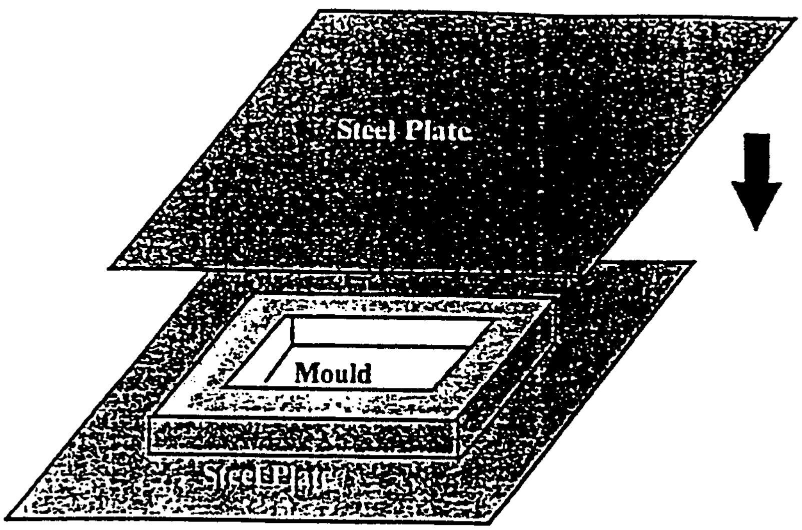

Figure 1 - Schematic drawing of fiber pressing mold for hot press.

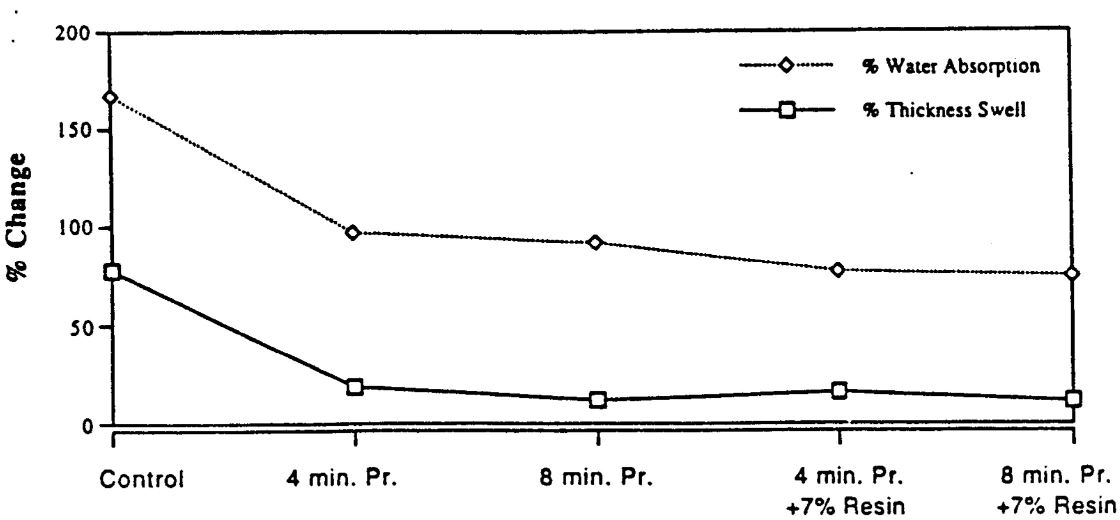

Figure 2 - Effect of 24 hr water soak on thickness swelling and water sorption.

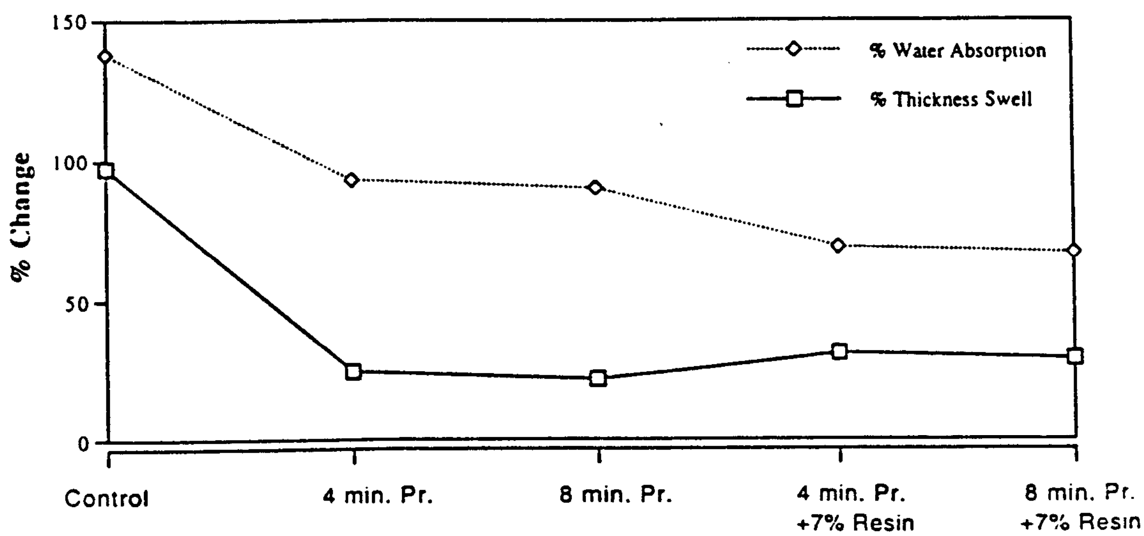

Figure 3 - Effect of 2 hr boiling on thickness swelling and water sorption.

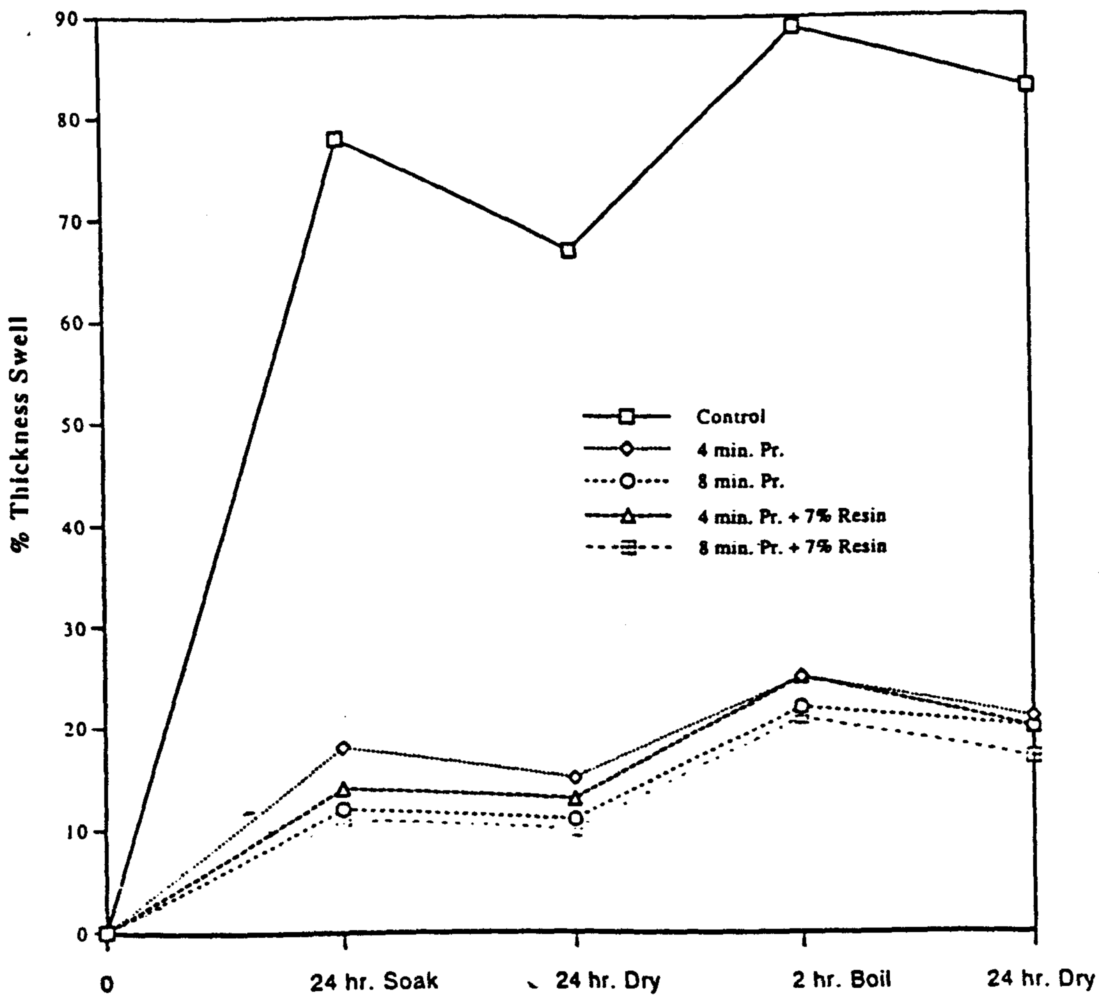

Figure 4 - Cyclic test for thickness swelling.

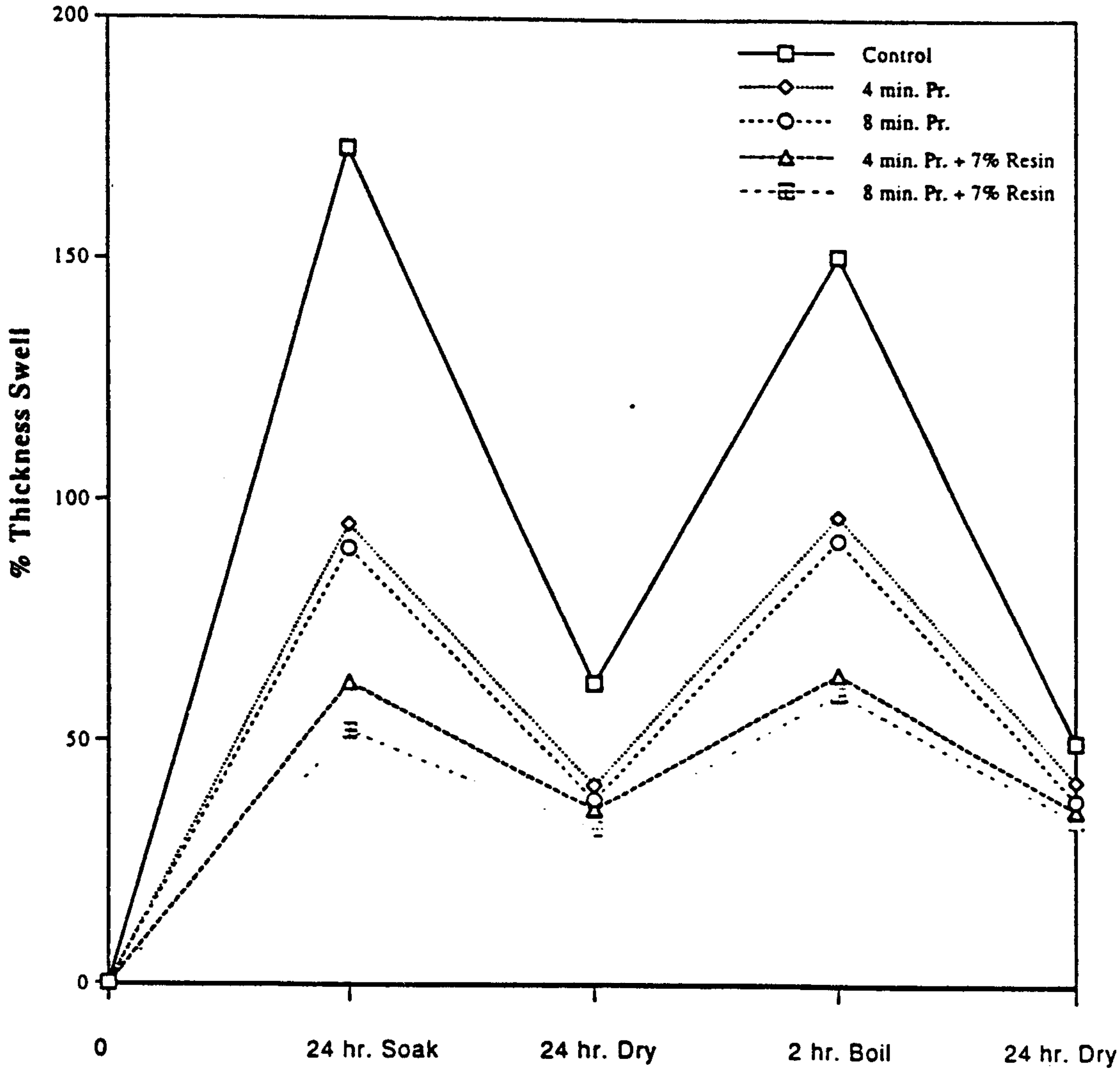

Figure 5 - Cyclic test for water sorption.

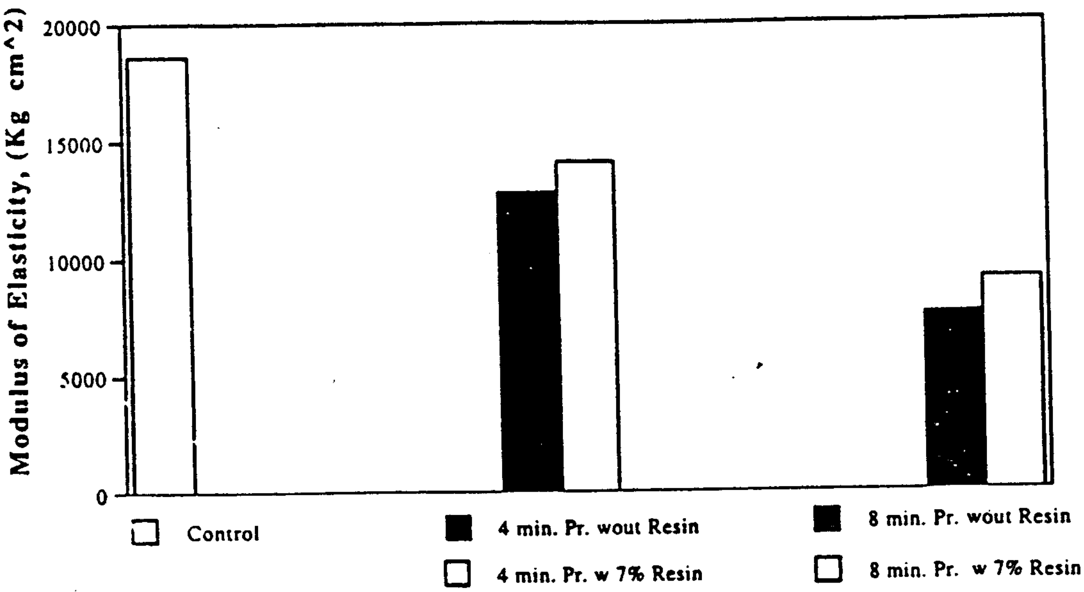

Figure 6 - Effect of pressing time and resin content on modulus of elasticity of jute fiberboards.

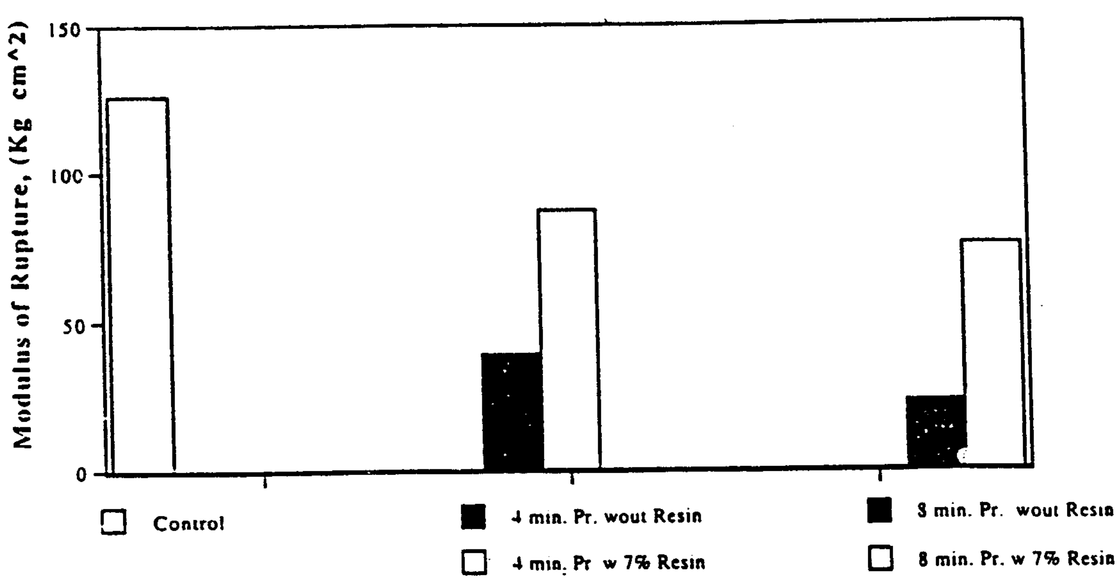

Figure 7 - Effect of pressing time and resin content on modulus of rupture of jute fiberboards.

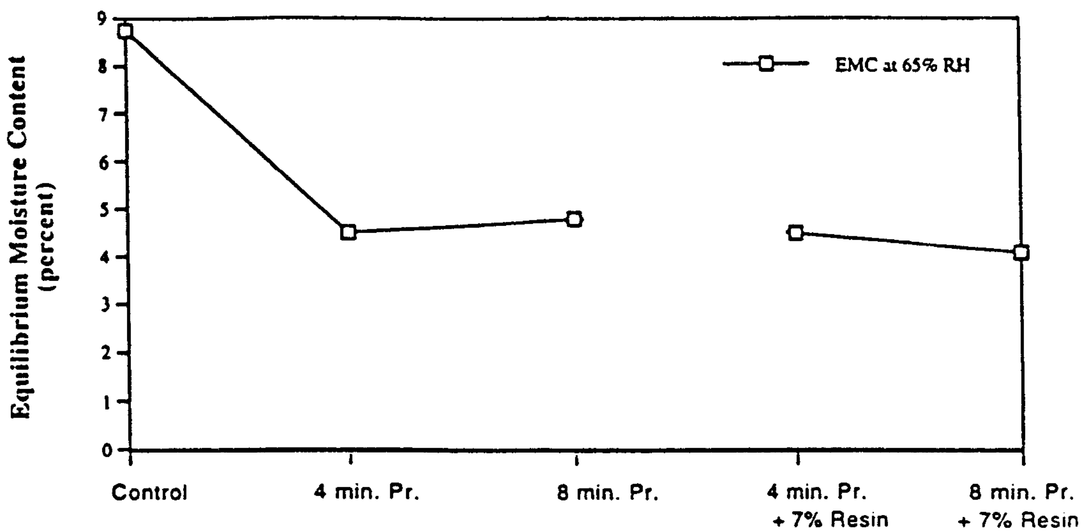

Figure 8 - Equilibrium moisture content (EMC) at 65% relative humidity of jute fiberboards.