Adhesion System in Bamboo Mat Board from Dendrocalamus Strictus – An Anatomical Study

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Abstract - *Bamboo is a versatile material for many diverse type of composite materials. In the recent developments, bamboo has been utilised in manufacture of many panel products like Bamboo mat Board (BMB), Bamboo Mat Corrugated Sheet (BMCS) etc. With the development of these kinds of products, the adhesion system also needs to be emphasised. Studying the bamboo-resin adhesion system is important for framing and designing the testing process and standardization of products. In this study the bamboo adhesive interphase in Bamboo Mat Board has been evaluated. The anatomical characterization of Dendrocalamus strictus was done. The depth of PF resin (adhesive) penetration into the bamboo anatomy was recorded. The adhesive interphase was measured and reported. The PF resin flow path was described. From the results, the PF resin (adhesive) penetration can be catagorised into Ground Tissue Penetration and Vascular Bundle Penetration and it can be concluded that the adhesive penetration in vascular bundle is higher than the parenchymatous cells in adhesion system of Bamboo Mat Board.*

Key Words: Bamboo mat board (BMB), bamboo anatomy, PF resin, adhesive interphase, flow path.

1. INTRODUCTION

Bamboo has been explored and stands out as an excellent panel material. It is also considered as an important plant fibre that has a great potential to be used in polymer composite industry. Its structural variation, mechanical properties, extraction of fibres, chemical modification, and thermal properties has made it versatile for use in the composite industry (1, 2). On the basis of earlier reports, bamboo has 60% cellulose with high content of lignin and its microfibrillar angle is 2 – 10^{o}, which is relatively small. This characteristic property has made bamboo fibre, as fibre for reinforcement in variety of matrices (1, 3). The use of bamboo in structural application is a rapidly developing new field of research which has the potential to change the way that infrastructure are constructed. The global research effort into the structural potential of bamboo has led to the development of numerous engineered products. There is extensive research in every possible field either in engineering, biotechnological, cultivation, etc. and trying to make one goal of utilizing bamboo in better way in composite industry. Studies in bamboo anatomy is very important to understand the properties of bamboo based products. Detailed study of bamboo anatomy of Asian Bamboos were done by Grosser.(4) Engineered bamboo is being increasingly explored for structural use in the construction sector.

Dendrocalamus strictus (Roxb.) Nees is also known as Calcutta bamboo or male bamboo. It is deciduous in nature and is one of the most important and commonly found bamboo species in India. *Dendrocalamus strictus* is distributed from China throughout India including Andaman Islands and Tarai regions of Himalayas, Nepal, Bhutan, Bangladesh, Sri Lanka, Myanmar, Pakistan, Thailand, Laos, Kampuchia, Vietnam mainly south central China, Malaysia, Singapore, Indonesia, Phillipians and Papua New Guinea (5). Owing to such a profound distribution, it has been effectively utilised in making many bamboo based panel products and composites. *Dendrocalamus strictus* was also found to have similar surface characteristics to commercial timber species (6). Therefore, in this study Bamboo Mat Board was manufactured with *Dendrocalamus strictus* and bamboo adhesive interaction was studied.

Bamboo mat board consists of compressed bamboo mat sheet material. Bamboo mat is the primary raw material for processing into Bamboo Mat Board. A uniformly woven bamboo mat is dimensionally stable, flexible and can be folded and spread as and when necessary. Bamboo mats are made by splitting bamboo into thin slivers of thickness of about 1 – 1.5 mm, and width 1.5 – 2 cm and then weaved manually. Mats are woven in two distinct patterns – rectangular pattern in which slivers remain at right angle to each other and herringbone pattern, in which the sliver remains at 45 degrees to each other(7). The Bamboo mats are dipped in resin and hot pressed to produce Bamboo mat board.

The objective of this study is to investigate the adhesion system of Bamboo Mat Board made from *Dendrocalamus strictus* in terms of bamboo anatomy. The study of bamboo adhesive interaction is important in order to design or frame the testing process and standardisation of Bamboo Mat Board. Therefore to design the glue line testing system of bamboo Mat Board, it is beneficial to know the morphology of bamboo-interphase system. Adhesive penetration in wood was studied by Mozdel (8). He coined the term 'interphase'. It is the volume in which both the wood cells and adhesive are present. 'Bondline' is the area which consists only of adhesive between two adherends. Adherends are the element which are connected by adhesive(8).

2. MATERIALS AND METHOD

Bamboo Mat Board prepared from PF resin (adhesive) and *Dendrocalamus strictus* was obtained from the Sample Cell of IPIRTI, Field Station Kolkata. 1 sample each were taken from 6 different locations from 6 randomly selected BMB boards for microscopic analysis.

Softening, Sectioning and Mounting:- The samples were placed in equal parts by volume of hydrogen peroxide (H_2O_2) and glacial acetic acid (CH_3COOH). The cubes were placed in Borosil reagent bottle and placed in hot air oven at 60ºC for 3 days. Upon cooling the blocks were sectioned with Reichert Sledge Microtome. The sections were subjected to regular ethanol series for dehydration. The sections were mounted in Canada balsam.

Maceration:- The process of maceration was done according to Jeffery's method(9). Thin slivers of bamboo were taken and placed at equal quantities of 10% nitric acid and 10% chromic acid contained in petridish and left for 24 hours. The slivers were then washed thoroughly in water, stained and mounted in Canada balsam.

Method of Analysis:- The average penetration of adhesive was calculated as the mean value of depth of adhesive penetration from the bondline into ground tissue and vascular bundles separately i.e

$$\text{Mean} = \frac{\sum_{i=1}^{n} y_i}{n}$$

Minimum 20 observations were made from each sample. Anatomical characterization and parameter measurements, microscopic penetration analysis and all quantitative analysis were done with Olympus CCD camera DP27 and Image Analysis Software - Olympus cellsens Dimension.

3. RESULT AND DISCUSSION

Bamboo Mat Board used in this study was made from *Dendrocalamus strictus* therefore its anatomical characterization was done and is given in Table 1.

In Bamboo Mat Board manufacturing, the primary processing of the bamboo slivers which are woven into mats, the surface section that comes in contact with the adhesive is the tangential section of the bamboo. Hence, the adhesive penetration is from the tangential section of the bamboo slivers. Microscopical observation of the bondline and interphase was done and Image of bondline and interphase in Bamboo Mat Board is provided in Fig.1. It can be observed that the resin penetration in parenchymatous cells are uniform and homogeneous whereas in the resin penetration of the vascular bundle, the fibre strand of the vascular bundle hinders the direct adhesive flow to the central vascular strand, resulting that depth of the adhesive in parenchyma cells adjoining the fibre strand is more, thus showing the flow path of the PF Resin into the Central Vascular Strand. Schematic representation of adhesive penetration in ground tissue and vascular bundles is provided in Fig. 2. The PF Resin penetration in BMB was measured. The average adhesive penetration in the ground tissue and Vascular bundle was measured separately and provided in Table 2. The maximum PF Resin penetration in Ground Tissue and Vascular Bundle of *Dendrocalamus strictus* was recorded. The range of adhesive penetration into these tissues were also recorded. It can be observed that the adhesive penetration depth in vascular bundle is more than that of ground tissue.

Table -1: Anatomical Characterization of *Dendrocalamus strictus*

Anatomical parameters	***Dendrocalamus strictus***
Mean fibre length. (µm)	1965
Mean fibre diameter. (µm)	16.91
Avg. fibre lumen diameter. (µm)	2.95
Avg. fibre wall thickness. (µm)	6.54
Avg. vessel lumina diameter. (µm)	203.52
Avg. parenchyma lumina diameter. (µm)	34.26
No. of Vascular Bundles/mm	4

Table -2: Anatomical Characterization of *Dendrocalamus strictus*

PF Resin penetration	**Ground Tissue penetration**	**Vascular Bundle penetration**
Avg. (µm)	77.93	149.36
Max. (µm)	182.23	362.19
Std. deviation	29.66	67.01
Range (µm)	33.01 – 182.23	57.34 – 362.19

Figure -1: Adhesive penetration in BMB

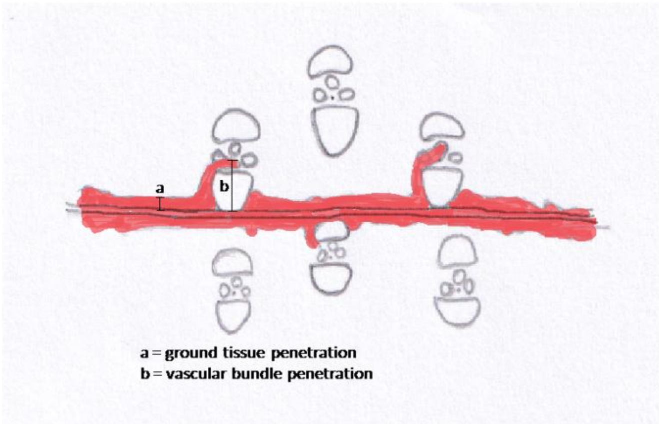

Figure -2: Schematic diagram of Bamboo Mat Board interphase region showing ground tissue penetration and Vascular bundle penetration (the fibre strand hinders the direct adhesive flow into the Central Vascular Strand)

4. CONCLUSIONS

In Bamboo Mat Board (BMB), the bamboo anatomy in surface of the slivers during primary processing of bamboo plays a major role in adhesive penetration system. The adhesive penetration in Bamboo Mat Board can be categorized into :- 1. Ground tissue penetration and 2. Vascular bundle penetration. The ground tissue penetration was less than vascular bundle penetration because of homogeneity and parenchymatous cells resulting in relatively uniform adhesive distribution in the tissue. The vascular bundle penetration was found to be greater because of its heterogeneity of the cells. In the region of the Vascular Bundle the fibre strand hinders the direct adhesive flow into the Central Vascular Strand. The Central Vascular Strand consists of xylem which is capable of containing maximum amount of adhesive (owing to its structure), phloem and parenchyma being thin walled cells are easily penetrable cells, therefore the Central Vascular Strand appears to be the region of maximum containment of adhesive in bamboo. On the contrary, fibre strands and sclerenchyma sheath are thick walled cells, thereby making adhesive penetration relatively difficult as compared to the other cells of Central vascular Strand. Therefore, it can be inferred that more the frequency of central vascular strand in the bondline would result in deeper interphase and hence, better the adhesion system in Bamboo Mat Board.

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