Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Md. Abdullah-Al-Mamun

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Supervisor(s): Md. Obaidullah Hannan, Professor, Forestry and Wood Technology Discipline, Khulna University

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PRODUCTION TECHNIQUE AND PROPERTIES OF BAMBOO-PLASTIC COMPOSITE USING *BAMBUSA BALCOOA*

B.Sc. (Hons.) Thesis

By

Md. Abdullah-Al-Mamun

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
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Supervisor

26.12.13

Md. Obaidullah Hannan

Professor

Forestry and Wood Technology Discipline

Khulna University, Khulna-9208

Bangladesh.

Prepared By

Md. Abdullah-Al-Mamun
26.12.13

Md. Abdullah-Al-Mamun

Student ID: 080528

Forestry and Wood Technology Discipline

Khulna University, Khulna-9208

Bangladesh.

Dedicated

To

My Late Uncles

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Abstract

(*Bambusa balcooa*) is locally distributed village bamboo mostly abundant in northern western and central districts of our country. Owing to its versatility, bamboo is used in BPC production as raw material. Therefore, Bamboo–plastic composite (BPC) is an environmentally progress way of combining plastics and bamboo chips. The composite typically consists of two major elements: bamboo particles and thermoplastic. The study evaluated two parameters: (1) the mass ratio of bamboo particles and PP (Polypropylene) and (2) pressing time, where pressure and temperature was remain constant. The results showed that pressing time and bamboo plastic ratio has a great impact on board quality. The modulus of Rupture (MOR) of BPC for differnt pressing time and ratio was found to 21.70 N/mm^2, 24.05 N/mm^2, 15.75 N/mm^2, 17.18 N/mm^2, 13.20 N/mm^2 and 14.95 N/mm^2 respectively. The modulus of elastcity (MOE) of BPC for differnt pressing time and ratio was found to 1314.5 N/mm^2, 2155.84 N/mm^2, 978.94 N/mm^2, 1200.03 N/mm^2, 690.23 N/mm^2 and 800.25 N/mm^2 respectively. The density of BPC for different ratios and different pressing time was 0.95 g/cm^3, 1.05 g/cm^3, 1.03 g/cm^3, 1.01 g/cm^3, 0.93 g/cm^3 and 1.02 g/cm^3 respectively. It was found that the moisture content of BPC boards for different types of ratios and pressing time was 5.64%, 6.03%, 5.85%, 6.87%, 5.9% and 7.16% respectively. It was found that the absorption of water by BPC boards for different types of ratios and pressing time was 12.2%, 6.8%, 10.06%, 20.31%, 29.20% and 26.7%, respectively after 242 hours immersion in water. The thickness swelling of BPC boards for different types of ratios and pressing time was 1.56%, 1.06%, 2.80%, 2.50%, 3.84% and 3.08% respectively after 24 hours immersion in water. The linear expansion of BPC for different types of ratios and pressing time was found 0.84%, 0.48%, 1.91%, 1.80%, 3.75% and 3.05% respectively after 24 hours immersion in water. From all the particle boards, the board of bamboo-plastic ratio 60: 40 at 30 minutes pressing time shows highest performance. Hence it can be concluded that plastic bonded board from Bamboo can be an alternative raw material for manufacturing of plastic bonded board.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In Bangladesh, bamboo is a common natural resource and widely used as a raw material for construction, furniture, pulping, and handy-crafts, which leads to many by-products (bamboo shavings and sawdust) from the bamboo-processing industry. But, resources have a limit. So far, those limits have not been met but with current consumption patterns and a growing world population, resources and land to harvest these resources are becoming scarce. There is a need to a real shift in resource management based on reduction and the use of renewable resources. To meet the demand of expending pressure, alternative raw materials are major concern of the world. Bamboo, one of the fastest growing renewable resources in the world, could play a major role in a society shifted for an alternative resource use. One of the alternative uses of bamboo is the manufacture of Bamboo thermoplastic composites (BPCs) is becoming popular day by day.

BPC is a composite with a rapid growing usage consisting of a mixture of bamboo waste and polymeric material (Soury *et al.* 2009). The term BPCs refers to any composites that contain plant (including bamboo and non-bamboo) fibers and thermo-sets or thermoplastics. Thermosets are plastics that, once cured, cannot be melted by repeating. These include resins such as epoxies and phenolics, plastics with which the forest products industry is most familiar. Thermoplastics are plastics that can be repeatedly melted. This property allows other materials, such as bamboo fibers, to be mixed with the plastic to form a composite product. Polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC) are the widely used thermoplastics for BPCs and currently they are very common in building, construction, furniture and automotive products (Panthapulakkal *et al.* 2006).

Bamboo plastic composites (BPCs) are a new generation of the composites experiencing considerable growth in production and demand in many countries. The global BPC market has experienced double- digit growth in North America and Europe, and the demand for BPCs in the United States is expected to reach $2.4 billion in 2013. A wide range of polymers; such as polypropylene, polyethylene, polyesters, etc as well as lignocelluloses; such as bamboo flour, bamboo fibers, hemp, linen, etc are used for their production.(Jiang *et al.* 2003 & John, 2004)

BPC has become currently an important address of research that gained popularity over the last decade especially with its properties and advantages that attracted researchers such as: high durability, Low maintenance, acceptable relative strength and stiffness, fewer prices relative to other competing materials, and the fact that it is a natural resource (Bengtsson and Oksman, 2006) & (Winandy *et al.* 2004). Other advantages have been strength points including (Wechsler and Hiziroglu, 2007): the resistance in opposition to biological deterioration especially for outdoor applications where untreated timber products are not suitable, the high availability of fine particles of bamboo waste is a main point of attraction which guarantees sustainability, improved thermal and creep performance relative to unfilled plastics where It can be produced to obtain structural building applications including: profiles, sheathings, decking, roof tiles, and window trims.

Present world is very concerned about environmental pollution. All the formaldehyde based resin binders are more or less toxic and injurious to health. One of the composite materials that have attracted interest worldwide is the inorganic bonded panels. Considering these aspects manufacture of bamboo plastic composites from bamboo particles were attempted.

Bangladesh is a densely populated country. The problem of housing is becoming more and more acute with the increase in its population. Moreover, natural disasters like flood are very frequent, and humid weather prevails in most part of the year. The situation, therefore, demands low cost housing for the teeming millions that would very likely promote the use of BPC panels as constructional material. In this context, the present study was undertaken to evaluate the suitably of *bambusa balcooa* in the fabrication of BPC.

1.2 Objectives of the Study

The objectives of this study are-

1. To develop the manufacturing technology for producing bamboo plastic composite board from *Bambusa balcooa.*

2. To determine the physical and mechanical properties of bamboo plastic board.

CHAPTER TWO

LITERATURE REVIEW

2.1Bamboo plastic composites

2.1.1 Definition

The acronym 'BPC' covers an extremely wide range of composite materials that use plastics ranging from PP to PVC and binders/fillers ranging from bamboo flour to natural fibers (e.g. flax) (Rails *et al.* 2001). BPCs are true composite materials and have properties of both bamboo and plastic. BPCs exhibit stiffness and strength properties between those for plastic and bamboo, but the density is generally higher than the individual components. The properties of BPCs come directly from their structure; they are an intimate mix of bamboo particles and plastic. The plastic coats the bamboo particle as a thin layer. The properties of BPCs can be tailored to meet the product requirements by varying the species and geometry of bamboo or plastic. For example, PE based products are cheaper and have a higher heat distortion temperature than the PVC based products but the PVC products are easier to paint and post treat (Anonymous, 2003). Pigments, UV stabilizers and fire retardants can all be added to the BPC raw material before extrusion to improve specific properties. BPCs have good stiffness and impact resistance properties, dimensional stability, resistance to rot, excellent thermal properties and low moisture absorption (Maldas and Kokta, 1993).

2.1.2 Applications of the BPC products

Advantages, desired properties, environmental regulations, and awareness have led to the substitution of using conventional bamboos with the BPC. Its production is growing over time due to its several applications (Adhikary *et al.* 2008). Main motives include:

- It can be molded in any particular mold with a variety of shapes and angles, so it can give any desired design.
- It can be treated in the same manner as the conventional bamboo using the same cutting and sawing equipment (Winandy *et al.* 2004).

Therefore, it is easy to use any conventional bamboo workshop with BPC products which have proven to give the same functionality as conventional bamboo in many areas (Wechslera and Hiziroglu, 2009). Various BPC products are available in the US market substituting some of the conventional bamboo products such as outdoor deck floors (Winandy *et al.* 2004). It is also used for railings, fences, landscaping timbers, siding, park benches, molding and trim, window and door frames, panels and indoor furniture (Winandy *et al.* 2004). In addition, Bamboo plastic composites can also substitute neat plastics in applications where the need for an increase in stiffness is an addition; where the bamboo fiber elasticity is almost 40 times higher than that of polyethylene and the overall strength is approximately 20 times greater (Bengtsson and Oksman, 2006). It has also higher thermal and creep performance compared to plastics and thus could be used in many structural building applications (Wechslera and Hiziroglu, 2009).

2.1.3 Material used in BPC

Bamboo and plastics (virgin or recycled) with various types, grades, sizes, and conditions are the main materials utilized in BPC production. BPC is composed mainly from a plastic matrix reinforced with bamboo and other additives sometimes are added using the appropriate processing procedures. Several ingredients of BPC are found in literature. Najafi *et al.* 2007, mentioned that BPC is a composite composed from a natural fiber/filler (such as kenaf fiber, bamboo flour, hemp, sisal etc.) which is mixed with a thermoplastic. They added that virgin thermoplastic materials (e.g. high and low density polyethylene (LDPE and HDPE), polypropylene (PP), polyvinyl chloride (PVC)) are commonly utilized. In addition, any recycled plastic which can melt and be processed in a temperature less than the degradation temperature of the bamboo filler (200 C) could be used to produce BPC (Najafi *et al.* 2007). Morton and Rossi 2003, said that the huge majority of BPC utilizes polyethylene and they classified the types of plastic used in BPC as follow: polyethylene (83%), polyvinyl chloride (9%), polypropylene (7%), others (1%).

Clemons and Caufield added that bamboo flour is obtained from bamboo wasted from bamboo processors. They said also that it should be from high quality and free of bark, dirt, and other foreign matter. Moreover, species are mainly selected based on regional availability of high quality flour and color. Pine, oak, and maple are the most common used in the United States (Clemons and Caufield, 2005). Adhikary *et al.* 2008, used recycled and virgin high density polyethylene (HDPE) with wood flour (Pinus radiata) as filler. The HDPE utilized was obtained from a plastics recycling plant and sawdust was collected from a local sawmill (Adhikary *et al.* 2008).

In this study, polypropylene and bamboo granule was used for manufactured BPC.

2.1.4 Manufacturing Process

The manufacturing of thermoplastic composites is usually a two-step process. The raw materials are first mixed together, and the composite blend is then formed into a product. The combination of these steps is called in-line processing, and the result is a single processing step that converts raw materials to end products. Compounding is the feeding and dispersing of the lignocellulosic component in a molten thermoplastic to produce a homogeneous material. During compounding various additives are added and moisture is removed. The compounding treatment will affect some properties of the products (Hwang and Hsiung, 2000). Some research about the effect of different couple agents and lubricants on bamboo-plastic composites have also been done (Harper and Wolcott, 2004; Herrera-Franco and Valadez-Gonza´lez, 2004; Lu *et al.* 2000). The compounded material can be immediately pressed or shaped into an end-product while still in its molten state or become a kind of small, regular pellets for future reheating and forming (Clemons, 2002). The use of compatibilisers (maleated polypropylene of different maleic anhydride content) in the compounding step improved the mechanical properties of the composites in dry conditions regardless of the compounding process; however, in wet conditions a decrease in tensile and flexural strength was observed for all composites (Bledzki *et al.* 2005).

Three common forming methods for BPC are extrusion (forcing molten composite through a die), injection molding (forcing molten composite into a cold mold), and compression molding (pressing molten composite between mold halves) Extrusion is by far the most common method (Clemons, 2002), the total poundage of products produced with injection and compression is much less than that is produced with extrusion (English *et al.* 1996).

2.1.5 Advantage of BPC Over Other Materials

The fact that BPC ingredients are mainly composed from bamboo and plastic has led to the rapid worldwide growth of its production due to the high availability of non-utilized plastic and bamboo wastes. Dividing the subject into two main sub-subjects, the plastic waste has the highest contribution regarding its huge available quantities which gives a strong advantage to BPC. The market potential regarding the usage of plastic waste into other utilizations is huge due to the high amounts of its disposition which constitutes the largest share of the global municipal and industrial solid waste. Kikuchi *et al.* 2008, mentioned that the plastic waste constitutes more than 60% of the total MSW, 22% was recovered and 78% disposed (Kikuchi *et al.* 2008). In United States, the waste of plastics; in 2005, was calculated as 11.8% of the 246 million tons of MSW generated (USEPA 2006). In India, Plastic in municipal solid waste makes up to 9–12% by weight of the total in addition to other wastes which may contain much higher proportions of plastics (Panda *et al.* 2010). The majority of the plastic wastes generated are disposed (Kikuchi *et al.* 2008). However, the continuous growth of worldwide plastic consumption due to its short life cycle compared to other products; roughly 40% have duration of life cycle smaller than 1 month, and the legislations of many countries concerned with minimizing landfills content and incinerators have led to a necessity of recovering plastic waste instead of disposing (Kikuchi *et al.* 2008) & (Panda *et al.* 2010). Incineration and land filling alternatives were rejected by several countries due to their potential danger to the environment either by polluting air or land; which results in not closing the loop of Cradle to Cradle and therefore depleting natural resources. As a consequence, the tendency towards recycling has increased (Jayaraman and Bhattacharyya, 2004). Some attempts for plastic recovery resulted during 2004 in a recovery of almost 8.25 million tons (39% of total amount of plastics consumed) in Western Europe; 35,000 tons (13.48% of total imported virgin plastics) in New Zealand (Adhikary *et al.* 2008). While in 2005, the United States recycled around 5.7% of the total plastics generated (USEPA 2006). On the other hand, some states in the US like Michigan have a recycling rate that is close to 100% (Beg and Pickering, 2008). In Brazil, some potential in recycling have been raised where around 15% of all plastics consumed are recycled and returned to industry (Beg and Pickering, 2008).

Therefore, the tendency towards recycling plastic instead of other options made it better for the sake of BPC production increase in the future. On the other hand, bamboo waste has a significant contribution to the total amount of waste especially that it comes from various commercial, industrial, and residential activities; which could include scrap lumbers, pallets, sawdust, tree stumps, branches, twigs, bambooen crates and pallets, building construction and demolition, furniture manufacturing, and many others. In addition, it is one of the main environmental concerns stated by many countries. In the United States, a report that was written in 1995 by CIWMB (California Integrated Waste Management Board) tells that severe problems concerned with landfill disposing were revealed (CIWMB 1995). It tells that the construction and demolition of buildings; which are mainly bamboo waste, generates almost twelve percent of all solid waste in California. Furthermore, the average fee for disposing of a ton of waste in a California landfill is about $30 to $35, but disposing of a ton of bamboo at a bamboo processing facility may only cost $10. In addition, the amount of wasted bamboo disposed in landfills in some regions in California reaches 90 percent of the total bamboo waste (CIWMB 1995). Adhikary *et al.* 2008, stated that a large amount of bamboo waste is generated from bamboo industry at different stages of the processing of bamboo; which is disposed mostly in landfills; Besides, the hazardous content of the bamboo waste are numerous and takes time to decompose (Adhikary *et al.* 2008). The Department of Environmental Quality (DEQ) in the United States reported that the other alternative; that used to be used, to get rid of bamboo wastes instead of disposing was burning (DEQ 2009). Bamboo burners were used at first and as a result of their environmental hazards; represented in huge amount of smoke & ash generated directly to the atmosphere polluting air and ambient, were shut down and prohibited from being used (DEQ 2009). Currently, a tremendous shift is done in the area of bamboo burning especially with the developed ideas of avoiding the environmental hazards. Therefore, the use of bamboo waste in BPC helps to overcome disposal and burning hazards and costs (Adhikary *et al.* 2008).

BPCs aim to increase the efficiency of bamboo usage by up to 40% compared to traditional bamboo processing. BPCs also provide other environmental benefits, such as:

- They use residual bamboo (eg. sawdust) and recycled plastic.
- BPCs contain no formaldehyde or volatile organic compounds.
- BPCs are potentially recyclable since it can be reground and processed.
- BPCs are considered nonhazardous waste and can be disposed of by standard methods. The basic material structure of BPCs shows that leaching from BPCs is minimal to non-existent (Anonymous, 2003).

2.1.6 Market potential

The awaiting market for BPC is huge due to the high production of plastics and bamboo which constitutes a significant amount of solid waste which is mostly disposed not recovered (Adhikary *et al.* 2008). Najafi *et al.* 2007, mentioned that BPC presents a promising raw material source for new value added products due to the large amount of daily waste generation and low cost (Najafi *et al.* 2007). BPC commercial products are increasingly replacing many products in many applications especially the construction related ones (Yeh *et al.* 2009). BPCs have gained an ever larger share; especially for decks and other outdoor structures (Youngquist *et al.* 1992). Other production lines of fencing, roofing, and siding have started to get a noticeable market share (Winandy *et al.* 2004). BPC usage is extensively spread especially in strips; where bamboo peel layers are tilted in the same direction, used in furniture industry (Augutis, 2004). BPC is also used in producing panels where it is produced by mixing bamboo flour and plastics giving a material which can be processed similar to 100% plastic-based products (Wechsler and Hiziroglu, 2007). Approximately one-half of all industrial materials used in the United States are bamboo-based; thus, the finding that the BPC market is increasing is not a surprise. The growth of BPC decking in the U.S. has started from less than 1 % in mid-90's to over 10% today with growth projected by several studies to reach 20% before the end of 2010 (Winandy *et al.* 2004). Two large sectors, the decking and fencing sector, the siding and roofing sector started to use the BPCs commercially in the U.S. (Winandy *et al.* 2004). Concerning the decking and fencing in the U.S., a study was done in 2002 which showed that there were 1.4 million new houses constructed (for single families) and 0.3 million new houses for multi-families; where the house averaged about 215 m^2 made from bambooen decks (Winandy *et al.* 2004). Winandy *et al.* 2004, concluded that all this huge amount of consumed bamboo could be substituted by BPC. The U.S. decking market alone uses a sum total of nearly 18.5 million m^3 of bamboo where 90% uses natural treated bamboo and 10% BPC (Winandy *et al.* 2004). In addition, the U.S. fencing market was divided into 45% bamboo, 44% metal, 7% plastic and 5% other material (Winandy *et al.* 2004). It was calculated at $US 2.6 billion in 2002 and was expected to grow approximately 5% per year and therefore a great potential of BPC domination was expected (Winandy *et al.* 2004).

2.1.7. Current status of BPC production

Although the BPC industry is still only a fraction of a percent of the total bamboo products industry, it has made significant inroads in certain markets. According to estimates, the BPC market was 320,000 MT in 2001 and the volume is expected to more than double by 2005. (www.plastemart.com).

2.2 General information of Bamboo (*Bambusa balcooa)*

2.2.1 General Description

Bamboo (bash) is a perennial, giant, bambooy grass belonging to the group angiosperms and the order monocotyledon. The grass family Poaceae (or Gramineae) can be divided into one small subfamily, Centothecoideae, and five large subfamilies, Arundinoideae, Pooideae, Chloridodeae, Panicoideae, and Bambusoideae. In distinction to its name, bamboos are classified under the subfamily Bambusoideae. (Wang and Shen, 1987) stated that there are about 60 to 70 genera and over 1,200 – 1,500 species of bamboo in the world. About half of these species grow in Asia, most of them within the Indo-Burmese region, which is also considered to be their area of origin. Sbamboo genera are Bambusa, Chusquea, Dendrocalamus, Phyllostachys, Gigantochloa and Schizostachyum.

Most bamboos are large and complex plants that remain in a vegetative state for many years, have flower only occasionally. Bamboos have an erratic flowering habit and flower at long intervals. The flowering cycle ranges from 3-120 years, and in most cases between 15-60 years. Most of the bamboo species die after gregarious flowering.

The most traditional vegetative propagation method is offset planting. A lower part of a single culm with the rhizome axis basal to it is an offset. Offsets are collected just before the monsoon (April-May) and planted with the onset of the monsoon. An offset becomes a matured harvestable clump in three years.

(Boa and Rahman, 1987). published a provisional list of fungal diseases of bamboo. The pathogens are: Dilozythiella bambusina causes leaf- spot disease. Puccinia sps. causes rust disease in leaves and sheaths of some bamboo species. Ustilago shiraiana, a smut fungus, attacks branches of Bambusa sps. Sarocladium oryzae causes serious die-back and blight disease in Bambusa balcooa, B. tulda and B. vulgaris. While in external use as posts, fences, etc termites and fungi destroy bamboo in about one or two years. If treated with preservatives bamboo may last for 15 years. CCB (copper sulphate, sodium dichromate and boric acid in 2:2:1) solution is a good preservative. Bamboo is treated in two different methods, namely sap displacement and soaking with this preservative.

Table 2.1: Bamboo (*Bambusa balcooa*) at a glance

Comon name	Bamboo
Botanical name	*Bambusa balcooa*
Local name	Silbarua, hilbarua, tellibarua, barak, balku, boira, bara-bans, gita-bora, bora-bans
Family	Poaceae or Gramineae
Plant type	perennial, giant, bambooy grass
Height	14-15 meter
Rate of growth	High, daily increment of 15 to 18 cm (5 to 7 inches).
Salt tolerance	low
Soil requirements	well drained sandy to clay loom, soil pH of 5.0 to 6.5
Water requirements	High drought tolarence, avoid flooding and long standing water.
Light requirements	High
Pest or diseases	rust disease in leaves and sheaths of bamboo species, Sarocladium oryzae causes serious die-back and blight disease in Bambusa balcooa
Propagation	offset planting, germination in three years, monsoon (April-May)
Life span	15 years
Biomass (above ground) of 100 bamboos (metric ton)	3.70
Number of culms per metric ton	27
Uses	Use for food containers, skewers, chopsticks, handicrafts, toys, furniture, flooring, pulp and paper, boats, charcoal, musical instruments and weapons. In Asia, bamboo is quite common for bridges, scaffolding and housing.

(Anon, 2009)

2.2.2 Natural Habitat and Distribution

Most of the bamboos need a warm climate, abundant moisture, and productive soil, though some do grow in reasonably cold weather (below –20o C).

According to (Grosser and Liese, 1971), bamboos grow particularly well in the tropics and subtropics, but some taxa also thrive in the temperate climate of Japan, China, Chile and the USA. Lee *et al.* 1994 stated that, the smaller bamboo species are mostly found in high elevations or temperate latitudes, and the larger ones are abundant in the tropic and subtropics areas. Bamboo is quite adaptable. Some bamboo species from one country have been introduced to other countries. The most popular and valuable bamboo species in Asia, Phyllostachys pubescenes or the Moso bamboo has been grown successfully in South Carolina and some other Southeastern states in America for more than 50 years. Bamboos are also adaptable to various types of habitat. They grow in plains, hilly and high-altitude mountainous regions, and in most kinds of soils, except alkaline soils, desert, and marsh. Abd.Latif and Abd.Razak, 1991 mention that bamboo could grow from sea level to as high as 3000 meter. Bamboo is suitable on well drained sandy to clay loom or from underlying rocks with pH of 5.0 to 6.5.

2.2.3 Bamboo Forest areas in Bangladesh

Bamboo Forest	Area (ha)
Sylhet	13964 (Drigo, *et al.* 1988).
Chittagong Hill Tracts	110439 (FMP 1993, p.55)
Chittagong	52471(FMP 1993, p.72)
Cox's bazar	34499 (De Milde *et al.* 1985)
Bamboo in Tea Estate(Private)	10118 (choudhury 1984)
Total area of Forest bamboo	221491
Total area of Village bamboo	270000 (FMP 1992)
Total bamboo area	491,491

2.2.4 Morphology and Growth

Wong, 1995; McClure, 1967; and Dransfield, 1992 illustrate the morphological characteristics of bamboo. Bamboo is divided into 2 major portions, the rhizomes and the culms. The rhizome is the underground part of the stem and is mostly sympodial or, to a much lesser degree, monopodial. This dissertation is concerned with the upper ground portion of the stem, called the culm. It is the portion of the bamboo tree that contains most of the bambooy material. Most of bamboo culms are cylindrical and hollow, with diameters ranging from 0.25 inch to 12 inches, and height ranging from 1 foot to 120 feet. It is without any bark and has a hard smooth outer skin due to the presence of silica. The culm is complimented by a branching system, sheath, foliage leaves, flowering, fruits and seedlings. Bamboo is a fast growing species and a high yield renewable resource. Bamboo growth depends on species, but generally all bamboo matures quickly. Aminuddin and Abd.Latif, 1991 stated that bamboo might have 40 to 50 stems in one clump, which adds 10 to 20 culms yearly. Bamboo can reach its maximum height in 4 to 6 months with a daily increment of 15 to 18 cm (5 to 7 inches).

2.2.5 Uses

Different Uses of bamboo are given below:

Food: The young shoot of Melocanna baccifera, Dendrocalamus longispathus, D. hamiltonii and Bambusa tulda are used as food. The yield of edible-shoot ranges from 3 to 30 tons per hectare per year. No information is available about total production.

Medicine: A valuable medicine, Tabashir or Banslochanis occasionally found inside the culm internodes of Bambusa bambos, Dendroclamus strictus and Melocanna baccifera. It is also an important ingradient for preparing famous Ayurbedic medicine, " Chawanprash" commonly used as a cooling energy tonic, aphrodisiac, cure to chronic cough and old age weakness. No information is available about total production.

Ornamentals: Bambusa polymorpha and B.vulgaris variety striata are used as ornamental bamboo.

Raw materials for handicrafts, utensils, and construction: Bamboo is the principal raw materials for rural constructions, cottage industries for making handicrafts, utensils and furniture, pulp and paper and transport construction. A total of 706.3 million bamboos were used for making these items in Bangladesh in 1993.

Other uses: Raw materials for basket making, furniture, novelties, agricultural implements, fishing rods, frames for fishing nets, walking sticks, handles of some tools, musical instruments, bullock carts, containers etc. Dry bamboo leaves are extensively used as fuel bamboo and green leaves as fodder in the rural Bangladesh. Bamboo rhizomes are sold to brick klins at the rate of 600 to 800 Taka (USD 10 to 13.34) per ton. Considering the wide range of uses as construction materials it is called the **"poor men's timber".**

CHAPTER THREE

MATERIALS AND METHODS

3.1 Collection and Preparation of Sample

Bamboo (*Bambusa balcooa*) is collected from Gollamari bazar, Batiaghata Upozilla under Khulna District as raw material for the manufacturing of Bamboo Plastic Composite board. For the purpose of preparing samples a medium size bamboo is selected and then it chipped by chopper machine. After chipping, the bamboo chips are run into grinder machine, by which the chips turned into particle. In this study the size of bamboo Particle ranges < 2mm is used. The PP (Polypropylene) granules that is collected from local market, which is available as raw material.

3.2 Selecting Variables

There are two types of variables, i.e. dependent and independent. In this study, temperature and pressure are the dependent variable. Temperature is fixed at 180°c and pressure is 4 mpa. According to Jan Benthien & Heiko Thoemen, (2012) temperature has little effect on mechanical properties of BPC board. Different study shows that 4 mpa pressures are better for producing good quality BPC board. On the other hand, melting temperature of polypropylene is ranges 130-160°C. So that fixing temperature at 180°C is very reasonable for this study.

Beside this, bamboo-plastic ratio and pressing time are the independent variables. Bamboo and plastic are quite difference in their nature, i.e. bamboo is hydrophilic and plastic is hydrophobic. A lot of study proved that bamboo-plastic ratio combination has a great effect on BPC board. Nadir A. *et al.,(* 2011) say that time condition has a vital impact on mechanical and physical properties also.

Table 3.1: Specifications of manufactured BPC boards

No of boards	6
Ratios (Particle : PP)	60:35/ 65:35/ 70:30
Parameter (Ratio, pressing time)	2
Temperature (°c) Fixed	180
Pressure(MPa) Fixed	4
Pressing time (min)	25, 30
Bending agent	PP (Polypropylene)
Layer	Single

Table 3.1: Board manufacturing considering with two Parameters

Sample no.	Bamboo Particle :PP	Pressing time
1	60:40	25
2	60:40	30
3	65:35	25
4	65:35	30
5	70:30	25
6	70:30	30

Flow Diagrams of BPC Board Production

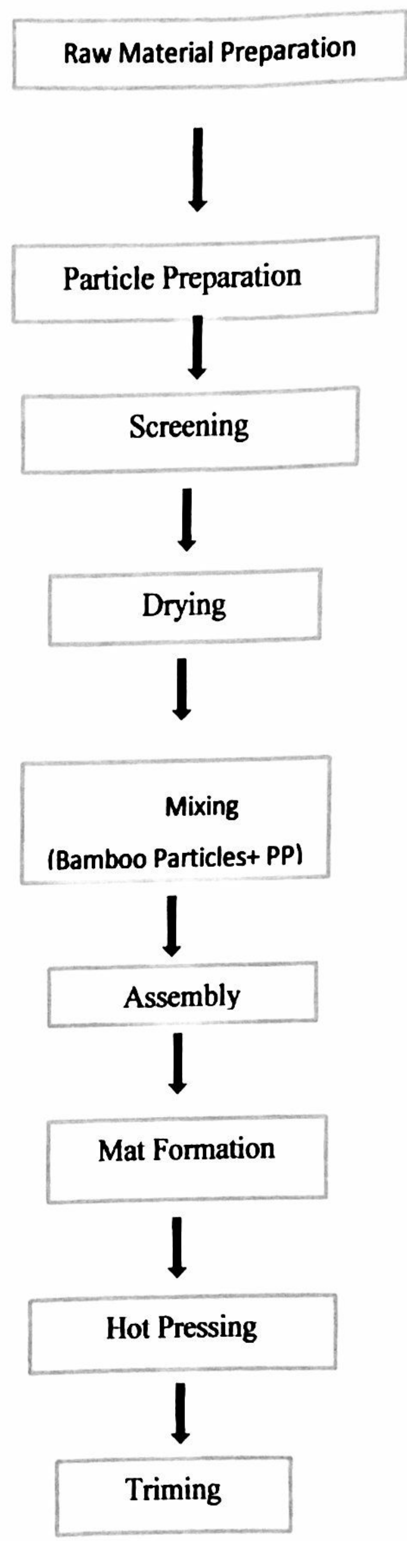


Fig. Flow diagrams of BPC board production

3.4 Determination of Mechanical Properties

All the samples are cut into required dimension for testing mechanical properties. The laboratory test for characterization of mechanical properties is carried out in the laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh.

3.4.1 Modulus of Rupture (MOR)

Modulus of Rupture (MOR) is measured by the University Testing Machine (UTM), Model no: UTM-100, maximum capacity-100000 kgf. MOR was calculated by the following formula-

$$MOR = \frac{3pl}{2bd^2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(1)$$

3.4.2 Modulus of Elasticity (MOE)

Modulus of Elasticity (MOE) is measured by the University Testing Machine (UTM), Model no: UTM-100, maximum capacity-100000 kgf. MOE is calculated by the following formula-

$$MOE = \frac{pl^3}{4\Delta bd^3} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(2)$$

Where, p = load in N, l = span length in mm, b = width of the test specimen in mm, d = thickness of test specimen in mm and Δ = deformation of the board in mm.

3.5 Determination of Physical Properties

All the samples are cut into (5cm × 5cm) dimension for testing physical properties. The laboratory test for characterization of physical properties is carried out in the laboratory of Forestry and Bamboo Technology Discipline, Khulna University, Bangladesh. At first all the specimens are weighted and green dimension are taken at room temperature. Then all the samples are kept into oven for 24 hours. After drying oven dry weight and dry dimension are also measured. Next, the samples are soaked into water for 120 hour. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

$$Density = \frac{Weight\ of\ Wood}{Standard\ Volume}$$

$$Moisture\ Content = \frac{Green\ Weight - Oven\ Dry\ Weight}{Oven\ Dry\ Weight} \times 100$$

Water absorption:

Water absorption was calculated by the following formula-

$$Aw = \frac{m2 - m1}{m1} \times 100$$ (http://www.imal.it)

Where,

Aw=Water absorption (%)

m1=Weight of the sample before immersion in water (gm.)

m2= Weight of the sample after (24 hr.) immersion in water (gm.)

Thickness swelling:

Thickness swelling was calculated by the following formula-

$$Gt = \frac{t2 - t1}{t1} \times 100$$ (http://www.imal.it)

Where,

Gt= Thickness swelling (%)

t1= Thickness of the sample before immersion in water (gm.)

t2= Thickness of the sample after (24 hr.) immersion in water (gm.)

Linear Expansion:

Linear Expansion was calculated by the following formula-

$$LX\ (\%) = \frac{LA - LB}{LB} \times 100$$ (http://www.imal.it)

Where,

LX= Linear Expansion (%)

LB= length of the sample before immersion in water (gm.)

LA= length of the sample after (24 hr.) immersion in water (gm.)

CHAPTER FOUR

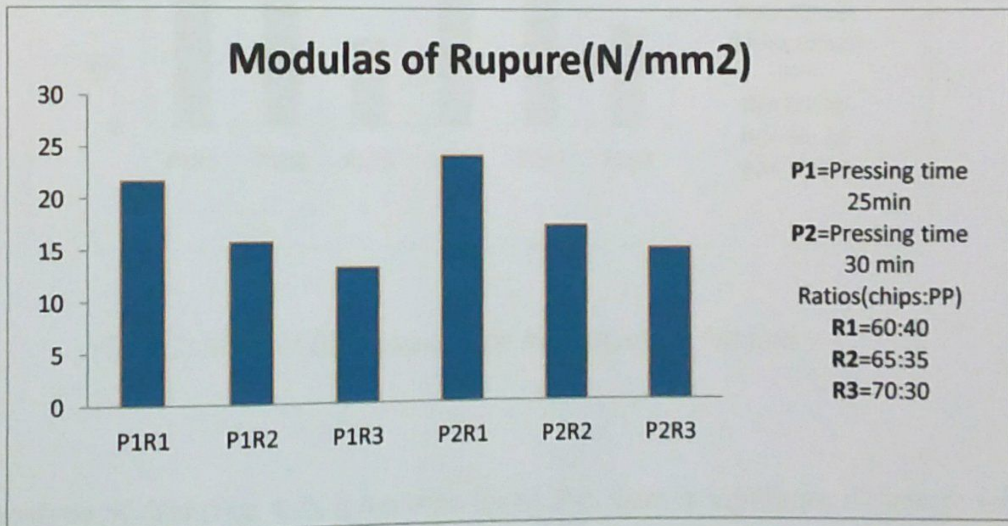
RESULTS AND DISCUSSION

The results of different physical and mechanical properties that were found during different laboratory tests are delineated (with standard error bar) here.

4.1 Mechanical Properties

4.1.1 Modulas of Rupture (MOR)

The modulus of Rupture of BPC for differnt pressing time and rotio was found to 21.70 N/mm^2, 24.05 N/mm^2, 15.75 N/mm^2, 17.18 N/mm^2, 13.20 N/mm^2, 14.95 N/mm^2 respectively. The MOR of BPC treatd particles of 60:40 ratio at 30 min pressing time was found to higher than other types of boards which may due to the higher density and slenderness ratio of the stm partcles than other types of partles. Other causes behind this may be due to the removing of extraneous materials from particles.

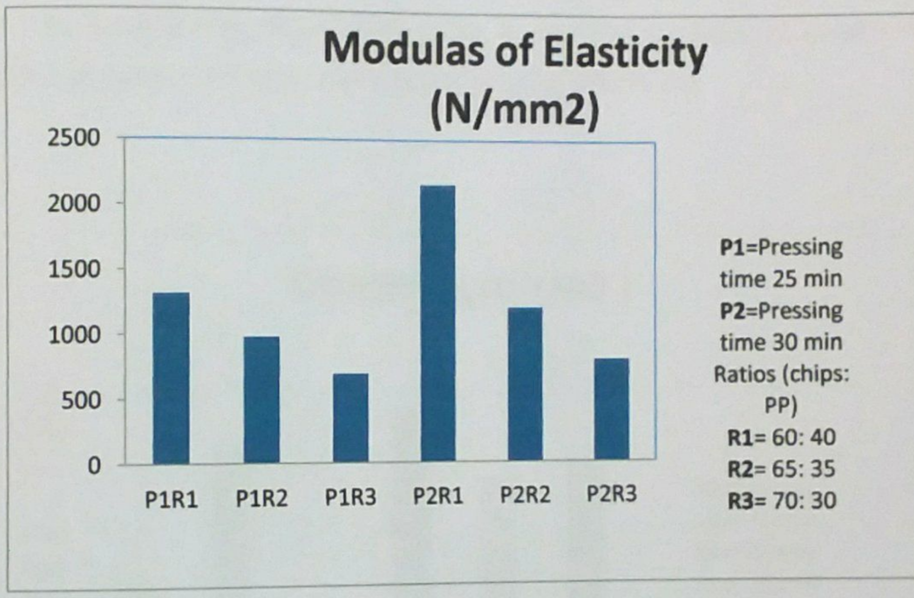


Fig; 4.1: MOR of BPC board made from *Bambusa balcooa*

From the analysis of data (Fig; 4.1), it has been found that, there is significant difference for different bamboo-plastic ratios and there is also significant difference for pressing time along with bamboo-plastic ratios.

4.1.2 Modulas of Elasticity (MOE)

The modulus of elastcity (MOE) of BPC for differnt pressing time and rotio was found to 1314.5 N/mm^2, 2155.84 N/mm^2, 978.94 N/mm^2, 1200.03 N/mm^2, 690.23 N/mm^2, 800.25 N/mm^2 respectively. The MOE of BPC treatd particles of 60:40 ratio at 30 min pressing time was found to higher than other types of boards. The variation that was found in MOE among the different tyes of BPC particleboards may be due to the same reasons for variation in MOR among the different types of particleboards.



Fig; 4.2: MOE of BPC board made from *Bambusa balcooa*

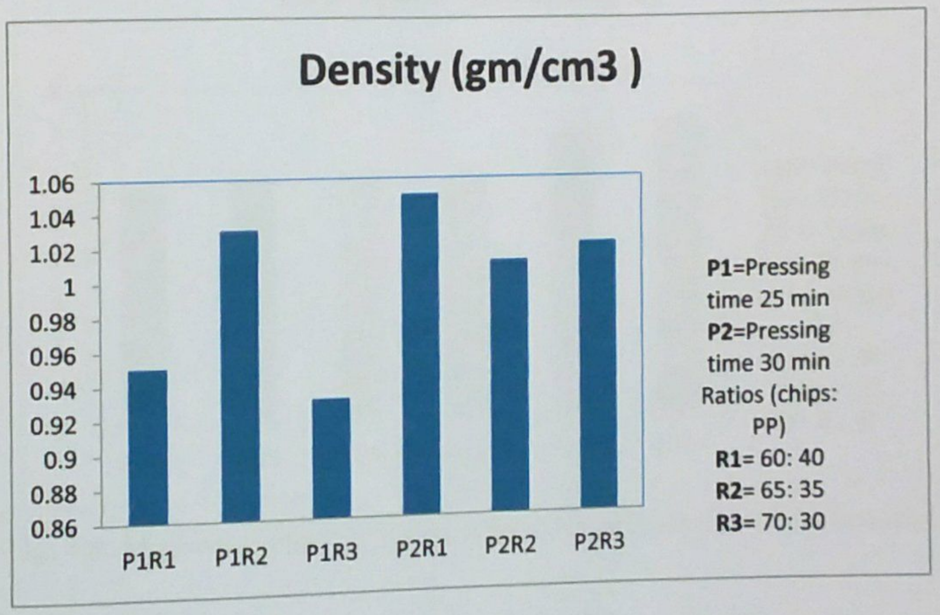
From the analysis of data (Fig; 4.2), it has been found that, there is significant difference for different bamboo-plastic ratios and there is also significant difference for pressing time along with bamboo-plastic ratios.

4.2 Physical Properties

4.2.1 Density

The density of BPC for different ratios and different pressing time was 0.95 gm/cm^3, 1.05 gm/cm^3, 1.03 gm/cm^3, 1.01 gm/cm^3, 0.93 gm/cm^3 and 1.02 gm/cm^3, respectively (Figure- 4.3). The variation in density among the different types of BPC may be due to the variation in density of the different raw materials itself. Particles of bamboo mainly consist of rigid fibers. Moreover the weight of the raw materials for different types of board was different.

Bamboo: PP ratio of 60:40 for 30 min pressing time show highest value and Bamboo: PP ratio 70:30 for 25 min pressing time show lowest value. It may also the cause of density variation among the different types of PP ratio used in manufacturing BPC board.



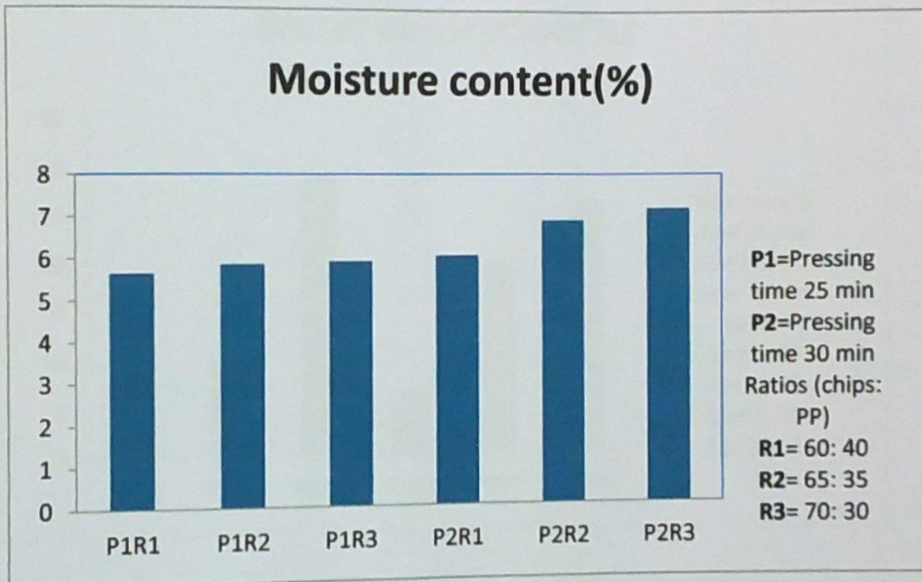
Fig; 4.3 Density of BPC board made from *Bambusa balcooa*

From the analysis of data (Fig; 4.3), it has been found that, there is significant difference in density for the different ratios and pressing time.

4.2.2 Moisture content

It was found that the moisture content of BPC boards for different types of ratios and pressing time was 5.64%, 6.03%, 5.85%, 6.87%, 5.9% and 7.16% respectively. Table-4.4 shows that the board of Bamboo: PP ratio of 70:30 with 25 minutes pressing time has the higher percentage of moisture content (7.16%). The causes behind this may be the lower amount of PP used.

The board of bamboo: PP ratio of 60:40 with 25 minutes pressing time shows 5.64%, the lowest amount of moisture content, which may due to the use of highest amount of PP and lowest amount of bamboo particle.

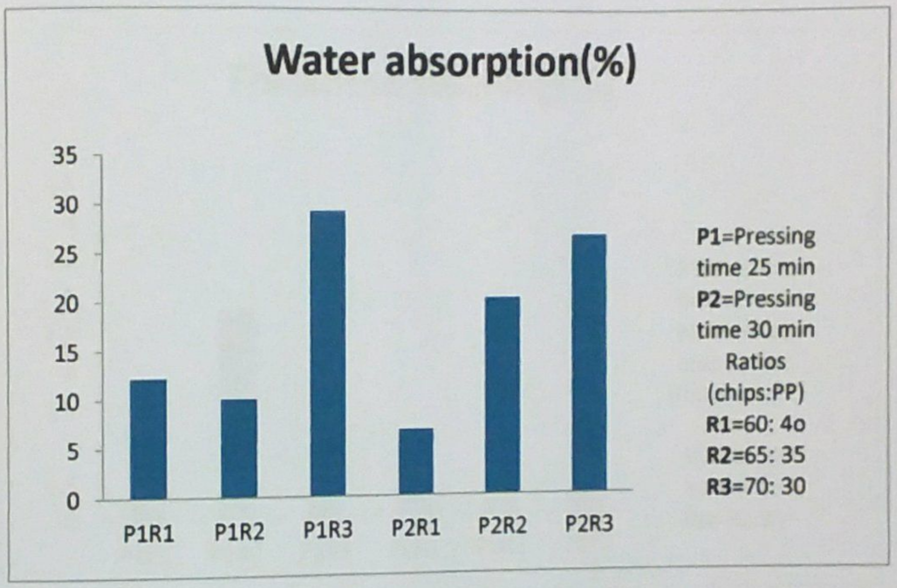


Fig; 4.4: Moisture content of plastic bonded board made from *Bambusa balcooa*

From the analysis of data (Fig; 4.4), it has been found that, there is significant difference for moisture content for the boards of different ratios and pressing time.

4.2.3 Water absorption

It was found that the absorption of water by BPC boards for different types of ratios and pressing time was 12.2%, 6.8%, 10.06%, 20.31%, 29.20% and 26.7%, respectively after 242 hours immersion in water. Table 4.5 shows that the board of bamboo: PP ratio of 70:30 for 25 minutes pressing time has the higher percentage of water (29.20%) absorption. The causes behind this may be higher amount of bamboo particle and also the lower amount of PP used. Board of bamboo: PP ratio of 60:40 for 30 minutes pressing time shows 6.8%, the lowest amount of water absorption, which may due to the use of high amount of PP and low amount of particles.

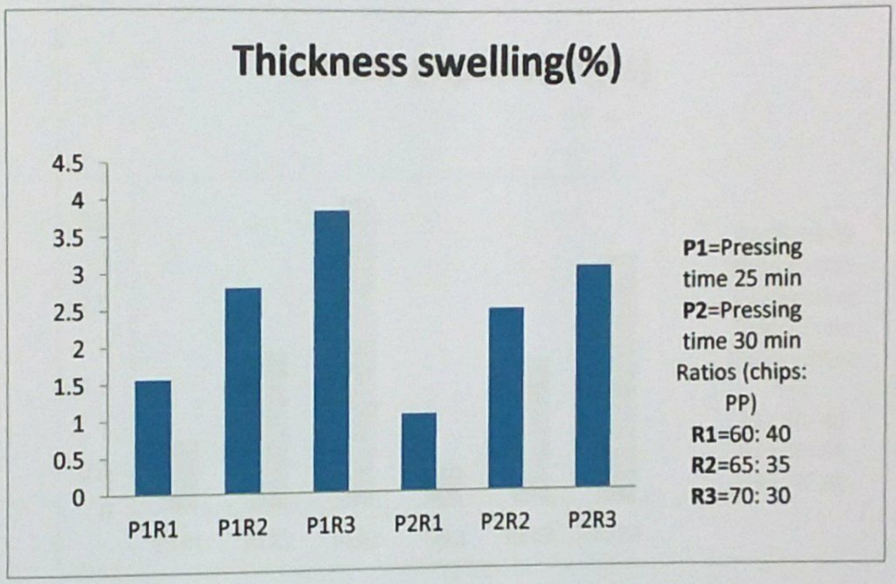


Fig; 4.5: Water Absorption of BPC board made from *Bambusa balcooa*

From the analysis of data (Fig; 4.5), it has been found that, there is significant difference for water absorption for the boards of different ratios and pressing time.

4.2.4 Thickness swelling

The thickness swelling of BPC boards for different types of ratios and pressing time was 1.56%, 1.06%, 2.80%, 2.50%, 3.84% and 3.08% respectively after 24 hours immersion in water (Fig;4.6). The variation in the thickness swelling among the different types of BPC's may be due to the variation in bamboo: PP ratio and different types of pressing time. Among the different ratios of bamboo: PP, the board of 70:30 ratio for 25 minutes pressing time had the highest (8.33%) and the board of 60:40 (bamboo: PP) ratio for 30 minutes pressing time had lowest (1.06%) thickness swelling than others. This may be due to the reason stated above as well as the lower pressure.

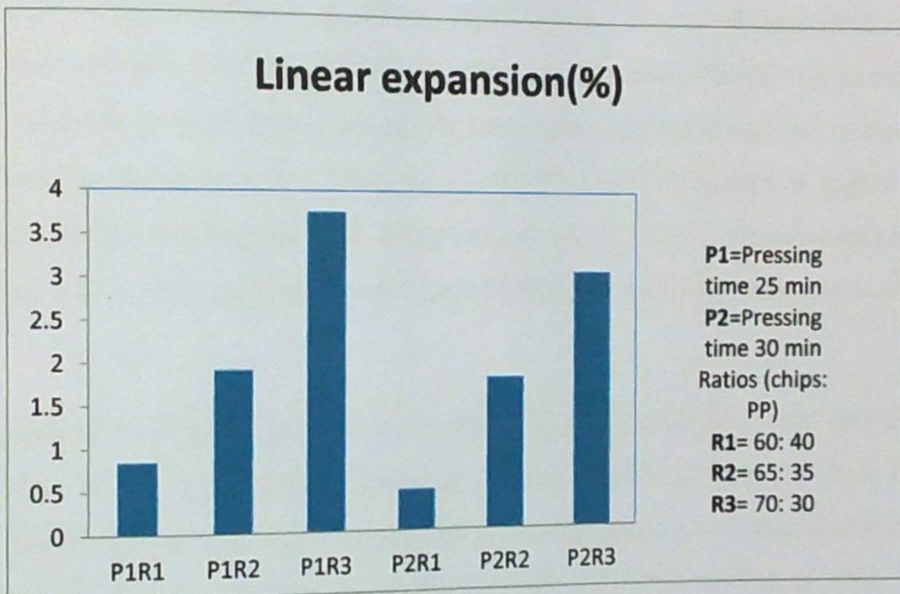


Fig; 4.6: Thickness Swelling of BPC board made from *Bambusa balcooa*

From the analysis of data (Fig; 4.6), it has been found that, there is significant difference for thickness swelling for the boards of different ratios and pressing time.

4.2.5 Linear expansion

The linear expansion of BPC for different types of ratios and pressing time was found 0.84%, 0.48%, 1.91%, 1.80%, 3.75% and 3.05% respectively after 24 hours immersion in water (Figure-4.7). The variation in the linear expansion among the different types of BPC's may be due to variation in bamboo: PP ratio and different types of pressing time. Among the different ratios of bamboo: PP, the board of 70:30 ratio for 25 minutes pressing time had the highest (3.75%) and the board of 60:40 (bamboo: PP) ratio for 30 minutes pressing time had lowest (0.48%) thickness swelling than others. This may be due to the reason stated above as well as the lower pressure.



Fig; 4.7: linear expansion of BPC board made from *Bambusa balcooa*

From the analysis of data (Fig; 4.7), it has been found that, there is significant difference for linear expansion for the boards of different ratios and pressing time.

4.3 Discussion

In this study, the average Modulus of Rupture (MOR) plastic bonded Bamboo ranges from 24.05 N/mm^2 to 13.20 N/mm^2 and MOE of plastic bonded bamboo ranges from 2155.84 N/mm^2 to 690.23 N/mm^2. The highest (24.05 N/mm^2) MOR shows chip: plastic ratio of 60: 40 for 30 minutes pressing time. MOE of plastic bonded particle board of chip: PP ratio 60: 40 for 30 minutes pressing time shows highest (2155.84 N/mm^2) value.

The strength properties were influenced by board density, with higher density boards possessing higher strength properties (MOR and MOE). These findings are in agreement with studies by Kwon and Geimer (1998), Ajayi (2002) and Zheng *et al.*, (2007). It was also reported by Wang and Sun (2002) and Papadopoulos *et al.*, (2002, 2004) that the density of particleboards made from wheat straw, coconut chips, and bamboo chips significantly affected the particleboard properties. The increase in water resistant properties as density increased was also in conformity with results from the experiment by Zheng *et al.*, (2007). Panel fabricated at higher density generally exhibits higher bending strength. It has been noted that higher plastic contents shows the higher density which ultimately shows the higher bending strength (Del Meneéis *et al.*, 2007) properties.

It has been remarked from the Fig; 4.1 that the MOR of bamboo plastic board arrived at the highest value 24.05 N/mm^2 for 30minutes pressing time and high bamboo: plastic ratio (60: 40). This strength (MOR) loss in bamboo is actually related to the progressive degradation of hemi-cellulose components due to increasing pressing time after a certain period of time. But for *Bambusa balcooa,* comparatively fiber length is long and long fiber particle boards can take high pressure to degradation of hemi-cellulose components. If we increase the pressing time more than 30 minutes the MOR will be decreased. Here 30 minutes pressing time is convenient for 60: 40 bamboo-plastic ratio boards.

On the other hand, as the ratio increases MOR of the boards are also increases. The highest strength of BPCs was measured when the lowest bamboo content is used and the strength decreased most severely when bamboo content increases (Shao-Yuan *et al.* 2011). It has also been observed that the MOE of bamboo composite board attained the highest value 2155.84 N/mm^2 for high bamboo plastic ratio of 60: 40.

From the chart (Fig; 4.2) an interaction effect exists between pressing time and ratio. The following figure Illustrated that high MOR and MOE values obtained when the pressing time ranges between 25 minutes to 30 minutes for high ratio ranges 60: 40 to 65: 35. The Fig. 4.2 also demonstrated that the MOR and MOE start to increase with the increase of pressing time.

Density is quantity that is used to describe the mass of a material per unit volume (Irle and Barbu, 2010). The density of a board depends on the density of particles as well as amount of PP used. This study reveals that the average density of BPC board is .1.00 gm./cm^3. In this observation, from the following figure-4.3, we have seen that bamboo plastic ratio and pressing time has the similar impact on density. Density is gradually increases with the increases of pressing time and plastic content in bamboo-plastic ratio. Highest density is obtained 1.05gm/cm^3, where bamboo content is 60% and pressing time is 30 min. The Lowest density is 0.93gm/cm^3 in which bamboo content is 70% and pressing time is 25 min.

It has been found that the moisture content of bamboo bonded particle board was ranges from (5-8) %. The chip: plastic ratio of 70: 30 shows the highest (7.16) moisture content and The chip: plastic ratio (60: 40) shows lowest (5.64%) moisture content among them. Following figure-4.4 demonstrated that with the increasing of bamboo-plastic ratio, the MC curve straightly decreases. Endra *et al.* (2012) stated that bamboo consists mostly of vessels in which moisture is absorbed. But plastic that has hydrophobic nature and tends to impede the entry of water into plastic board. Pressing time has not so effective as well as bamboo plastic ratio on MC. It has been found that, moisture content increasing very slightly with the increasing of pressing time. It's might be happened that increasing pressing time breakdown the structural bond of plastic and also increases the water affinity due to chemical bond with bamboo. But the effects of the present of high amount of plastic materials; we cannot recognize the effect of pressing time on MC.

Water absorption (WA) is lower in chip: plastic ratio of 60: 40 for 30 min pressing time. The WA of the various board specifications was higher where there was reduced proportion of plastic inclusion. Lowering the plastic proportion in composite manufacture might lead to large quantity of exposed particles and free internal spaces which are almost always associated with low density boards, a possible contributory factor to this WA pattern and likely instability of board. Compared to low density particleboards, high density particleboards have lower porosity so that particles and plastic can interact with each other more easily to form stronger crosslink (Zheng *et al.*, 2007).

Thickness swelling in this study ranges 3.84% to 1.06% and linear expansion 0.48% to 3.75%. The high moisture absorption of plant fibers leads to swelling and presence of voids at the interface (porous products), which results in poor mechanical properties and reduces dimensional instability of composites. Treatment of plant fibers with hydrophobic chemicals (i.e. Polypropylene) can reduce the moisture gain (Gassan and Bledzki, 2000; Espert *et al.* 2003). Similar result is found in this study, i.e. swelling properties decreases with the increasing of plastic content. High pressing time causes the thermal degradation of fiber structure and build up a new bonding particles with plastic (Gassan and Bledzki, 2000; Espert *et al.* 2003). These composite boards have achieved the lower water affinity character which reduces the swelling behavior. That's why board of 60: 40 ratios for 30 minutes pressing time has shown the lowest thickness swelling and linear properties. For the same reason board of 70: 30 ratios for 25 minutes pressing time has shown the height thickness swelling and linear properties.

No.of Boards	Ratio (BP:PP)	Pressing Time (min)	Physical Properties					Mechanical Properties	
			Density (gm/cm^{3})	MC (%)	WA (%)	TS (%)	LE (%)	MOR (N/mm^{2})	MOE (N/mm^{2})
1	70:30	25	0.9	8.9	29.2	3.84	3.75	13.2	690.23
2	65:35		0.92	7.1	14.2	2.8	1.91	15.75	978.94
3	60:40		0.95	6.02	12.2	1.56	0.84	21.7	1314.5
4	70:30	30	1.0	7.9	20.2	3.08	3.05	14.95	800.25
5	65:35		1.02	6.9	10.0	2.5	1.8	17.18	1203.21
6	60:40		1.05	5.85	6.8	1.06	0.48	24.05	2155.85

CHAPTER FIVE

CONCLUSION

Conclusion

1. Plastic (polypropylene) bonded particle board from *Bambusa balcooa* is a cheap constructional material and it can be manufactured from conventional process. It may solve the dwelling problem of poor people. Government should take some necessary steps for popularizing the bamboo plastic composites.

2. The height MOR and MOE of plastic bonded bamboo board is 24.05 N/mm2 and 2155.84 N/mm2 respectively for the ratio of 60: 40 in a pressing time 30 min. the MOR and MOE value of plastic bonded bamboo board can be enhanced by increasing the plastic bamboo ratio along with increasing the pressing time.

3. The lowest thickness swelling is1.06% and the lowest water absorption is 6.8 % for the ratios of 60: 40 at 30 min pressing time. Both thickness swelling and water absorption value of plastic bonded bamboo board can be reduced greatly with the increasing of board density as well as increasing pressing time.

4. Further study is necessary to improve the mechanical properties of plastic bonded bamboo boards.

References

Abd.Latif, M., and O. Abd.Razak. 1991. Availability, distribution of bamboo and its industrial status in Peninsular Malaysia. Proceedings 4th International Bamboo Workshop. Bamboo in Asia and the pacific. Chiangmai, Thailand. November 27 – 30. Pp. 60-67.

Adhikary, Kamal B., Shusheng Pang, and Mark P. Staiger, 2008. "Dimensional stability and mechanical behaviour of wood–plastic composites based on recycled and virgin high-density polyethylene (HDPE)." Composites: Part B, no. 39 : 807–815.

Allen O.N. and Allen E.K., 1981. The Leguminosae. The University of Wisconsin Press.1981: 812p.

Allen O.N. and Allen E.K., 1981. The Leguminosae. The University of Wisconsin Press.1981: 812p.

Aminuddin, M., M. Abd.Latif. 1991. Bamboo in Malaysia: Past, present and future research. Proceeding s 4th International Bamboo Workshop. Bamboo in Asia and the pacific. Chiangmai, Thailand. November 27 – 30. Pp. 349-354.

Anon. 2008a Oriented strand board. Wikipedia. Online document, Retrieval with Opera version 9.64, retrieved on October 30, 2009.

Anonymous, 2003. Wood plastic composites, A technical review on Materials, Processes and Application, Tangram Technology ltd , UK.

Augutis, V., Gailius, D., Balčiūnas, G., 2004. "Testing system for composite wood based strips." Measurement Technologies Laboratory (Faculty of Telecomunications and Electronics), no. Issue 285.

Ayrilmis N, Jarusombuti S, Fuengvivat V, Bauchongkol P., 2011. Effect of thermal treatment of rubber wood fibres on physical and mechanical properties of medium density fibreboard. J Trop Forest Sci ; 23:10 e 6.

Banik, R.L (2000). Silviculture and Field-Guide to Priority Bamboos of Bangladesh and South Asia. Publication of Bangladesh Forest Research Institute, Chittagong. ISBN984-753-033-3.

Banik, R.L (2000). Silviculture and Field-Guide to Priority Bamboos of Bangladesh and South Asia. Publication of Bangladesh Forest Research Institute, Chittagong. ISBN984-753-033-3.

Beg M.D.H. and Pickering K.L., 2008. "Reprocessing of wood fibre reinforced polypropylene composites. Part I: Effects on physical and mechanical properties." Composites: Part A, no. 39 : 1091–1100.

Bengtsson, Magnus, and Kristiina Oksman, 2006. "Silane crosslinked wood plastic composites: Processing and properties." Composites Science and Technology, no. 66: 2177–2186.

Bledzki A.K., Letman M., Viksne A., and Rence L., 2005. A comparison of compounding processes and wood type for wood fibre—PP composites. 36(6):789-797.

Boa, E. R. and Rahman, M. A. (1987). Bamboo blight and bamboos of Bangladesh. Forest Pathology Series, Bulletin 1 Bangladesh Forest Research Institute, Chittagong. pp 43.

Choudhury , M. R. (1984). A study on supply and demand of bamboos and canes in Bangladesh. FAO, Part of Project BGD/78/010. Field Document No. 9, Dhaka.

Clemons C., 2002. Wood-plastic Composites in the United States: The interfacing of two Industries. Forest Products Journal; Vol. 52(6): 10-18.

De Milde, R; Shaheduzzaman, M. and Chowdhury, J. A. (1985). The Kassalong and Rankhiang Reserved Forests in the Chittagong hill Tracts. Assistance to the Forestry Sector, Bangladesh, FAO/ UNDP Project, BGD /79/017. Field Document No. 10.]

Derringer G. and Suich R., 1980. Simultaneous optimization of several response variables. J. Qual. Technol., 12, pp. 214–219.

Dransfield, S. 1992. The bamboos of Sabah. Herbarium, Royal Botanic Garden, Kew, U.K. in association with Herbarium, Forest Research Centre, ForestryDepartment, Sabah, Malaysia. Sabah Forest Recoeds, No.14.

Drigo, R, M. Shaheduzzaman and J.A. Chowdhury (1988). Inventory of Forest Resources of Southern Sylhet Forest Division. Assistance to the Forestry Sector, Phase II. Bangladesh : FAO/ UNDP Project, BGD /85/085. Field Document No. 3.

Eero Sojstrom, 1993. Wood chemistry fundamentals and applications, Academic press.

English B., Clemons C.M., Stark N. and Schnieder J.P., 1996. Waste-wood derived fillers for plastics. Gen. Tech . Rep. FPL-GTR-91. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 282-291.

Espert A., Camacho W. and Karlsson S., 2003. Thermal and thermome-chanical properties of biocomposites made from modified cellulose and recycled polypropylene. Journal of Applied Polymer Science 89 (9), 2350–2353.

Fengel D. and Wegener G., 1983. Wood, Chemistry, Ultrastructure, Reactions. Walter de Gruyter, New York.

Gassan, J. and Bledzki A.K., 2000. Possibilities to improve the properties of natural fiber reinforced plastics by fiber modification – jute polypropylene composites. Applied Composite Materials 7 (5–6), 373–385.

Georgopoulos S. Th., Tarantili P.A., Avgerinos E., Andreopoulos A.G., Koukios E.G., 2005. Thermoplastic polymers reinforced with fibrous agricultural residues. Polymer Degradation and Stability 90(2), 303–312, special issue.

Grosser, D., and W. Liese. 1971. On the anatomy of Asian bamboos, with special reference to their vascular bundles. Wood Sci.Technol. 5:290 – 312

Harper D. and Wolcott M., 2004. Interaction between coupling agent and lubricants in wood–polypropylene composites, Applied Science and Manufacturing. 35(3):385-394.

Harrington E.C., 1965. The desirability function. Ind. Qual. Cont., 21, pp. 494–498.

Herrera-Franco P.J. and Valadez-Gonza´lez A., 2004. Mechanical properties of continuous natural fibre-reinforced polymer composites. Applied Science and Manufacturing. 35(3):339-345.

Hwang G.S. and Hsiung J.C., 2000. Durability of plastics/wood composite boards manufactured with waste wood particles, Taiwan Journal of Forest Science 15(2): 201-208. (in Chinese).

Irle M. and Barbu M.C., 2010. Wood-based panel technology. An introduction for specialists. Brunel University Press.

Jacob M. and Thomas S., 2008. Biofibres and biocomposites. Carbohy-drate Polymers. <www.sciencedirect.com>.

Jan T. Benthien and Heiko Thoemen, 2012. Effects of raw materials and process parameters on the physical and mechanical properties of flat pressed WPC panels. Composites: Part A 43 : 570–576.

Jayaraman, Krishnan, and Debes Bhattacharyya, 2004. "Mechanical performance of woodfibre-waste plastic composite materials." Resources, Conservation and Recycling Journal 41 , no. 4 : 307-319.

Jiang H., Kamdem D.P., Bezubic B. and Ruede P., 2003. Mechanical Properties of Poly (Vinyl Chloride)/Wood Flour/Glass Fiber Hybrid Composites. JVAT, 9(3): 138-145.

John K. and Naidu V., 2004. Effect of Fiber Content and Fiber Treatment on Flexural Properties of Sisal Fiber/Glass Fiber Hybrid Composites. J. Reinforc. Plast. Compos. , 23(15): 1601-1605.

Kauppinen T, Teschke K, Savela A. et al., 1997. International data base of exposure measurements in the pulp, paper and paper product industries. Int Arch Occup Environ Health, 70:119–127. Doi :10.1007/s004200050195. PMID: 9253640.

Kikuchi, Ryunosuke, Jan Kukacka, and Raschman Robert, 2008. "Grouping of mixed waste plastics according to chlorine content."Separation and Purification Technology 61, no. 1 : 75-81.

Klyosov A. A., 2007. *Wood-Plastic Composites,* John Wiley & Sons, Inc., Hoboken, New Jersey, 698 pp.

Kwon HE, Geimer RL. 1998. Impact of System Pressing Variables on the Dimensional Stabilization of Flake boards. For. Prod. J. 48(4): 55-61.

Lee, A.W.C., B. Xuesong, and N.P. Perry. 1994. Selected physical and mechanical properties of giant timber bamboo grown in South Carolina. Forest Prod.J. 44(9): 40 46.

Lu J.Z., Wu Q. and McNabb Jr. H.S., 2000. Chemical coupling in wood fiber and polymer composites: A review of coupling agent and treatments. Wood and Fiber Science, 32(1): 88-104.

Malaysia (FRIM) in collaboration with Forest Research Centre, Forestry Department, Sabah, Malaysia. Malayan Forest Records, No.41.

Maldas D. and Kokta B.V., 1993. Performance of hybrid reinforcements in PVC composites. Part I - Use of surf ace-modified mica and wood pulp as reinforcements. Journal of Testing and Evaluation., 2(1): 68-72.

Mathias L.J., Lee S., Wright J. and Warren S.C., 1991. Improvement of wood properties by impregnation with multifunctional monomers. J Appl Polym Sci; 42:55–7.

McClure, F.A. 1967. The bamboos, A fresh perspective. Harvard University Press. Cambridge, Massachusetts.

Nadir A., Songklod J., Vallayuth F. and Piyawade B., 2011. Effect of thermal-treatment of wood fibres on properties of flat-pressed wood plastic composites.

Najafi, Saeed Kazemi, Mehdi Tajvidi, and Elham Hamidina, 2007. "Effect of temperature, plastic type and virginity on the water uptake of sawdust/plastic composites." Holz Roh Werkst, no. 65 : 377–382.

Noel O. and Clark R., 2005. "Recent advances in the use of talc in wood-plastic composite", The 8th International Conference on Wood Fiber Plastic Composite Madison Wisconsin USA.

Ohlmeyer M. and Lukowsky D., 2004. Wood-based panels produced from thermal-treated materials: properties and perspectives. In: Proceedings of international conference on wood frame housing durability and disaster, Las Vegas, USA; October 4e 6, p.127 e131.

Orwa C, Mutua A, Kindt R, Jamnagass R, and Anthony S., 2009. Agroforest tree Database.; 491p.

Panda, Achyut K., Singh R.K. and Mishra D.K., 2010. "Thermolysis of waste plastics to liquid fuel: A suitable method for plastic waste management and manufacture of value added products - A world prospective." Renewable and Sustainable Energy Reviews 14, no. 1 : 233–248.

Panthapulakkal S., Zereshkian A. and Sain M., 2006. Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites. Bioresource Technology 97 (2), 265–272.

Rails T., Wolcott M.P. and Nassar J.M., 2001. Interfacial contributions in lignocellulosic fiber reinforced plastic composites. Journal of applied polymer science: 80: 546-555.

Satyavati GV, Gupta AK, Tandon N. Medicinal Plants of India, vol. II. Indian Council of Medical Research, New Delhi, 1987: 490p.

Shao-Yuan Leu, Tsu-Hsien Yang, Sheng-Fong Lo and Te-Hsin Yang, 2011. Optimized material composition to improve the physical and mechanical properties of extruded wood–plastic composites (WPCs). 24 November 2011.

Soury, E., Behravesh A.H., Rouhani Esfahani E. and Zolfaghari A., 2009. "Design, optimization and manufacturing of wood–plastic composite pallet." Materials and Design, no. 30: 4183–4191.

Stark N.M. and Rowlands R.E., 2003. Effects of wood fiber characteristics on mechanical properties of wood/polypropylene composites. Wood Fiber Science. 35(2): 167–174.

Tewari, D.N. 1992. A monograph on bamboo. International Book Distribution, Dehra Dun (India)

Wang, D. and S.J. Shen. 1987. Bamboos of China. Timber Press, Portland, Oregon.

Wang, S.G. and Xu, Y.I. 1994. Development of non-wood based composites in P.R. China. In: proceedings, 2nd pacific Rim Bio-based composite symposium, 6-9 November 1994, vacouver, Canada, pp. 227-234.

Wechsler A. and Hiziroglu S., 2007. Building and Environment 42 : 2637–2644.

Winandy J.E., Stark N.M. and Clemons C.M., 2004. "Consideration In Recycling Of Wood-Plastic Composites." 5th Global Wood and Natural Fiber Composites Symposium. Kassel - Germany.

Wolcott M.P. and Englund K., 1991. A Technology Review for Wood Plastic Composites. Proc. 33rd Inter. Particleboard Composite Materials Symp. Wasthington State University.

Wong, K.M. 1995. The bamboos of Peninsular Malaysia. Forest Research Institute

Yeh, Shu-Kai, Sushant Agarwal, and Rakesh K. Gupta, 2009. "Wood–plastic composites formulated with virgin and recycled ABS." Composites Science and Technology, no. 69 : 2225–2230.

Youngquist J., Myers G. and Harten T., 1992. Lignocellulosic – Plastic Composites from Recycled Materials. American Chemical Society, 1992.

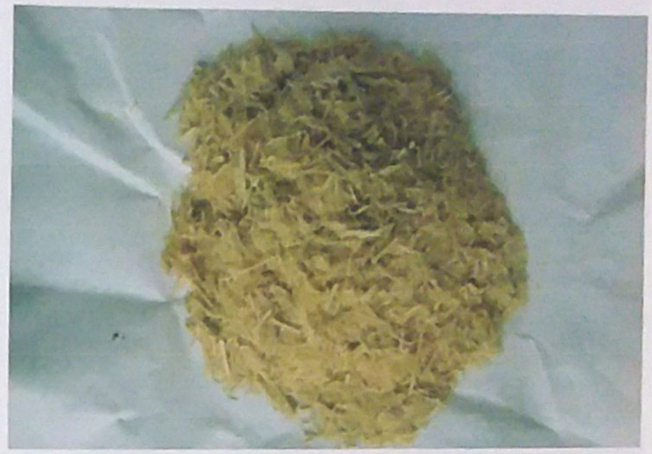
Zheng Y, Zhongil LP, Zhang RH, Jenkins BM, Blunk S. 2007. Particleboard Quality Characteristics of Saline Jose Tall Wheatgrass and Chemical treatment Effect. Bioresource Tech. 98(6): 1304-1310.

Zheng Y, Zhongli LP, Zhang RH, Jenkins BM, Blunk S, 2007. Particleboard Quality Characteristics of Saline Jose Tall Wheatgrass and Chemical Treatment Effect. Bioresource Tech. 98(6): 1304-1310.

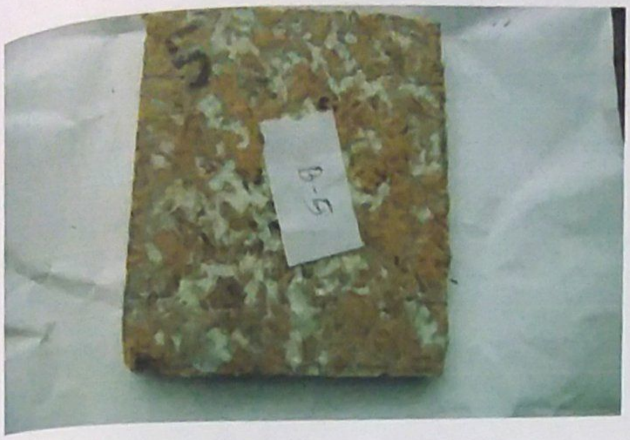
Zheng Y., Pan Z., Zhang R., Jenkins B.M. and Blunk S., 2005. Properties of medium density particleboard from saline Athel wood. Ind. Crops Prod. 23, 318-326.

Photo Gallery

Bamboo ***(Bambusa balcooa)*** **chips**



Particle boards made from (*Bambusa balcooa*)



No. of samples made from (*Bambusa balcooa*)

Duncan's Multiple Range Test for MOR

Level of PT	Level of Ratio	N	....VALUE.... Mean	SD
P1	R1	3	21.69667	3.427250
P1	R2	3	15.75667	2.477771
P1	R3	3	13.20000	0.825409
P2	R1	3	24.05000	0.945357
P2	R2	3	17.17666	0.929319
P2	R3	3	14.94666	0.118462

Duncan's Multiple Range Test for MOE

Level of PT	Level of Ratio	N	....VALUE.... Mean	SD
P1	R1	3	1314.48333	112.97908
P1	R2	3	978.93667	161.87900
P1	R3	3	690.23670	9.55303
P2	R1	3	2155.84000	95.27674
P2	R2	3	1200.03000	17.32051
P2	R3	3	800.26000	8.44631

Duncan's Multiple Range Test for Density

Level of PT	Level of Ratio	N	....VALUE.................. Mean	SD
P1	R1	3	0.95000	0.10000
P1	R2	3	1.03333	0.09073
P1	R3	3	0.93333	0.02081
P2	R1	3	1.05333	0.06429
P2	R2	3	1.01333	0.09073
P2	R3	3	1.02000	0.05000

Duncan's Multiple Range Test for Moisture Content

Level of PT	Level of Ratio	N	....VALUE.................. Mean	SD
P1	R1	3	5.64333	0.539666
P1	R2	3	5.85000	0.360555
P1	R3	3	5.90333	0.106927
P2	R1	3	6.03000	0.437369
P2	R2	3	6.87000	0.401497
P2	R3	3	7.15666	0.116762

Duncan's Multiple Range Test for Water Absorption

			….. ……….VALUE………………	
Level of PT	Level of Ratio	N	Mean	SD
P1	R1	3	12.21667	0.620670
P1	R2	3	10.05550	0.043589
P1	R3	3	29.16666	0.941134
P2	R1	3	6.81666	0.076376
P2	R2	3	20.31333	0.493288
P2	R3	3	26.70000	1.200000

Duncan's Multiple Range Test for Thickness Swelling

			….. ……….VALUE………………	
Level of PT	Level of Ratio	N	Mean	SD
P1	R1	3	1.56333	0.09504
P1	R2	3	2.790000	0.22745
P1	R3	3	3.846667	0.09504
P2	R1	3	1.060000	0.09000
P2	R2	3	2.476667	0.12503
P2	R3	3	3.076667	0.09073

Duncan's Multiple Range Test for Thickness Swelling

Level of PT	Level of Ratio	N	….. ……….VALUE………………	
			Mean	SD
P1	R1	3	0.843330	0.106930
P1	R2	3	1.913333	0.065064
P1	R3	3	3.750000	0.216564
P2	R1	3	0.476667	0.105040
P2	R2	3	1.806667	0.058595
P2	R3	3	3.053333	0.097125