Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Sraboni Deb

Title: Effect of the wood species and particle size on the properties of wood plastic composites

Supervisor(s): Dr. Md. Nazrul Islam, Professor, Forestry and Wood Technology Discipline, Khulna University

Programme: Bachelor of Science in Forestry

Effect of the Wood Species and Particle Size on the Properties of Wood Plastic Composites

Shraboni Deb

This dissertation has been prepared for the partial fulfillment of the requirements of Four (4) years professional B. Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA – 9208
BANGLADESH

2018

Effect of the Wood Species and Particle Size on the Properties of Wood Plastic Composites

Shraboni Deb

This dissertation has been prepared for the partial fulfillment of the requirements of Four (4) years professional B. Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA – 9208
BANGLADESH
2018

Effect of the Wood Species and Particle Size on the Properties of Wood Plastic Composites

COURSE TITLE: PROJECT THESIS
COURSE NO: FWT-4114

Shraboni Deb
Student ID: 130517

This dissertation has been prepared for the partial fulfillment of the requirements of Four (4) years professional B. Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.

Supervisor:

Dr.Md Nazrul Islam
Professor
Forestry and Wood Technology Discipline
Khulna University
Khulna, Bangladesh.

Prepared By:

shraboni deb

Shraboni Deb
Student ID. 130517
Forestry and Wood Technology Discipline
Khulna University
Khulna, Bangladesh.

Dedicated
To My
Beloved Parents &
Loving Sister Usmi

ACKNOWLEDGMENTS

First of all, I am very grateful to almighty God for successfully completion of my B. Sc. honor's project thesis. I would like to thank and express my gratitude to several people.

It is a great pleasure for me to express my gratitude, sincere appreciation, heart-felt indebtedness and profound respect to my honorable supervisor **Prof. Dr. Md Nazrul Islam,** Forestry and Wood Technology Discipline, Khulna University, Khulna for his continuous supervision, guidance, inspiration, valuable advices and thoughtful suggestions during the research period and for providing useful books and papers in preparing and writing up this thesis. Moreover, without his kind supervision and encouragement I could not come up with this paper.

I do express my thanks to my parents for their encouragement, sacrifice, affection and blessing that paved the way to my higher education.

I am deeply indebted and grateful to Nasim Rana, Khandkar-Siddikur Rahman, Md. Rafikul Islam and also some of my friends specially Amit Kumar Saha, Sabuj Majumder for helping me about my research project. I am also thankful to Md. Hanif Mian our laboratory assistant for helping me to complete the experimental work.

And finally at last I am extremely thankful to all my friends, well-wishers and classmates for their motivation and inspiration during this work.

January, 2018

Shraboni deb

Shraboni Deb

ABSTRACT

The objective of this work is to investigate the effect of hard wood species on Wood Plastic Composite and also the effect of particle size on the Composite. Polyethylene is a versatile polymer with numerous applications. Control of the molecular structure leads to low density (LDPE). Linear low density (LLDPE) and high density (HDPE) products with corresponding differences in the balance of properties

Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) were used as wood particle in wood plastic composite (WPC) board manufacturing and Polyethylene (PE) was used as binder. The study was conducted based on thre different ratios (FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40, CRK:PE-60:40)of wood particle and Polyethylene for manufacturing Wood Plastic Composite (WPC) board. It has been found that the density of four different ratios(FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40)of Wood Plastic Composite (WPC) board were 939.904kg/m3, 835.822kg/m3 and 965.998kg/m3 and 881.517kg/m3 respectively. The moisture content of four different ratios (FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40) were 1.86%, 2.71% and 1.54% and 2.35% respectively. The modulus of rupture (MOR) of four different ratios(FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40) of Wood Plastic Composite (WPC) board manufactured were found 20.6146 N/mm², 32.3414N/mm² , 25.1619 N/mm² and 38.494 N/mm² respectively and modulus of elasticity (MOE) of the four ratios were 1914.08N/mm², 2743.83 N/mm²,2406.35N/mm² and 3608.153N/mm² respectively. Although some properties of these boards have followed some international standards like, ANSI, IS, AS/NZS, BS and German standards. This study suggests that this board can be very feasible economically and environmentally.

Table of contents

List of Table

TABLE	CONTENTS	PAGE
Table 3.3	Specifications of manufacturing WPC Board:	
Table A-1	ANOVA for density	26
Table A-2	ANOVA for moisture content	26
Table A-3	ANOVA for Water absorption	27
Table A-4	ANOVA for Thickness swelling	27
Table A-6	ANOVA for MOR	28
Table A-7	ANOVA for MOE	28

List of Figure

Abbreviation

Anon	Anonymous
ANOVA	Analysis of Variance
APCC	Asian and Pacific Coconut Community
ASTM	American Society for Testing and Materials
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization of United Nations
g/cm^3 or gm/cm^3	Gram per cubic centimeter
Ha	Hectare
kg/m^3	Kilogram per cubic meter
kN	Kilo Newton
lb/ft^3	Pound per cubic feet
Cm	Centimeter
M	Meter
Mm	Millimeter
μm	Micro meter
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Mega Pascal
N/mm^2	Newton per square millimeter
PVC	Poly vinyl chloride
PE	polyethylene
PVAC	Poly-vinyl acetate
Rpm	Rotor per minute
SD	Standard deviation
UTM	Universal Testing Machine
WP	Wood particle

1.INTRODUCTION

1.1. Background of the study:

Wood is one of the lingo cellulosic materials and valuable forest resources on the earth and it conforms to the most varied requirements (Anon, 1982). About 70% demand for timber and 90% for fuel wood of the country is met from the trees grown in village groves of Bangladesh. Demand for wood resources was on the rise not only for fuel, but also for construction of ships and buildings, and consequently deforestation was widespread. Wood from times immemorial has been the most useful of all the readily available materials to mankind (Anon, 1982).

Wood plastic composite (WPC) is a type of composite that prepared from wood and thermoplastic. WPC is a composite with a rapid growing usage consisting of a mixture of wood waste and polymeric material (*Soury et al. 2009*). Though there are many researches in several decades still it is a new material for many people. Recently wood plastic industry has grown tremendously worldwide.Here will look back the development history of wood plastic industry below.

At the beginning, wood had been used as filler for thermoplastic with the utilization of recycled wood-chips or dust. It has some clear advantages in compare with inorganic fillers and reinforcements: lighter, less abrasive, renewable and low cost. It also improves stiffness and dimensional stability with minimal weight increase. There was limited use of wood plastic composite before 1980's decade because of unfamiliarity between wood and plastic industries. The first industrial experiment of WPC is the automotive interior that is manufactured by American Woodstock in 1983. They produced WPC panel substrates using Italian extrusion technology. Polypropylene with approximately 50% wood flour was extruded into a flat sheet that was then formed into various shapes for interior automotive paneling. This was one of the first major applications of WPC technology in United States (Huy Doan Dac, 2016).

These products include decorating boards, picnic tables and industrial flooring. Similar composites were also used in window and door component profiles. Today, the decorating market is the largest and fastest growing WPC market. Since the mid-1990s, activity in the WPC industry has increased dramatically with the rapid developed technology and many players joined the market (Craig, 2000).Growth in WPC market is truly impressive, from about 50,000 tons in 1995 to 600,000 tons in 2003, and reaches 1.3 million tons in 2015 for only US market. It takes 48% world market share, follow by China and Europe with respectively 33% and 9%. The building applications (especially decking and railing) is still the largest market of WPC, following by automotive interior and furniture. Growing demand for wood plastic composite as a low cost and environmentally friendly substitute to plastic and steel components in construction applications is expected to drive market growth.

1.2. Objective of the study:

- To investigate the effect of hard wood species on properties of Wood Plastic Composite.
- To assess the effect of particle size on properties of Wood Plastic Composite.

2. Literature Review

2.1 General Description of Wood Plastic Composite Board:

2.1.1. Definition:

Wood Plastic Composite boards are composite materials made of wood fiber/wood and thermoplastic (including PE, PVE, PP, and PET). Chemical additives seem practically "invisible" (except mineral fillers and pigments, if added in the polymer structure. They provide for integration of polymer and wood flour (powder) while facilitating optimal processing conditions (Clemons, 2002). In addition to WPCs can also contain other ligno-cellulosic and inorganic filler materials. Wood-plastic composite is also composed of wood from recovered saw dust and other cellulose based fiber fillers such as pulp fibers, peanut hulls, bamboo, straw, digestate, etc.

2.1.2. Uses of WPC products:

There are also application in the market, which utilize only virgin raw materials. Its most widespread use is in outdoor deck floors, but it is also used for railings, fences, landscaping timbers, cladding and siding, park benches, molding and trim, window and door frames, and indoor furniture. Advantages, desired properties, environmental regulations, and awareness have led to the substitution of using conventional woods with the WPC. Its production is growing over time due to its several applications (*Adhikary et al. 2008*). Main motives include-

- It can be moulded in any particular mold with a variety of shapes and angles, so it can give any desired design (*Takatani et al. 2007*).
- It can be treated in the same manner as the conventional wood using the same cutting and sawing equipment (*Winandy et al. 2004*).

2.1.3 Materials used in WPC Board:

Wood and plastics (virgin or recycled) with various types, grades, sizes, and conditions are the main materials utilized in WPC production. WPC is composed mainly from a plastic matrix reinforced with wood and other additives sometimes are added using the appropriate processing procedures. Mentioned that WPC is a composite composed from a natural fiber/filler (such as kenaf fiber, wood flour, hemp, sisal etc.) which is mixed with a thermoplastic (*Najafi et al. 2007*). 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 wood filler (200°C) could be used to produce WPC (*Najafi et al. 2007*). Huge majority of WPC utilizes polyethylene and they classified the types of plastic used in WPC as follow: polyethylene (83%), polyvinyl chloride (9%), polypropylene (7%), others (1%), (Morton and Rossi, 2003).

2.1.4 Advantages and disadvantage of WPC Board:

The fact that WPC ingredients are mainly composed from wood and plastic has led to the rapid worldwide growth of its production due to the high availability of non-utilized plastic and wood 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 WPC. 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.

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

- Compared with wood, it is not resistant to high temperature.
- They use residual wood (eg. sawdust) and recycled plastic.
- WPCs contain no formaldehyde or volatile organic compounds.
- WPCs are potentially recyclable since it can be reground and processed.
- WPCs are considered nonhazardous waste and can be disposed of by standard methods. The basic material structure of WPCs shows that leaching from WPCs is minimal to non-existent (Anon, 2003).

2.1.5 Current status of WPC production:

Although the WPC industry is still only a fraction of a percent of the total wood products industry, it has made significant inroads in certain markets. According to estimates, the WPC market was 320,000 MT in 2001 and the volume is expected to more than double by 2005 (Morton and Rossi, 2003).

2.2. Raw materials for particle board manufacturing:

2.2.1 Ligno- Cellulosic materials:

2.2.1.1 Woody Materials:

- ✓ Planer savings,
- ✓ Sawmill residues, such as slabs, edging, trimmings, etc.
- ✓ Residues from timber cutting in furniture and cabinet manufacturing plants,
- ✓ Residues from match factories,
- ✓ Veneer and plywood plant residues,
- ✓ Saw dusts,
- ✓ Logging residues, such as short logs, broken logs, crooked logs, small tree tops and branches, forest thinning , etc, and
- ✓ Bark (Salehuddin, 1992)

2.2.1.2 Non woody materials:

- ✓ Jute sticks,
- ✓ Bagasse,
- ✓ Bamboo,
- ✓ Flax shaves,
- ✓ Cotton stalks,
- ✓ Cereal straw,
- ✓ Almost any agricultural residue (such as husks, coconut coir etc.) after suitable treatment (Youngquist, 1999).

2.2.2 Chemicals

2.2.2.1 Binder or Adhesive:

Adhesives or binders are the materials used in the fabrication of timber structures and components offers a neat and efficient method of bonding together the separate pieces of wood, or of board products such as plywood, chipboard, or fiberboard, which comprise the finished product. ASTM (1997) defines an adhesive as a substance capable of holding materials together by surface attachment. The bond attained must meet the strength requirements for the structure as a whole and this bond must remain unaffected by the condition to which it will be exposed throughout its life (Youngquist, 1999).

Types of Adhesive / Binder:

There are mainly two types of adhesive. One originated from natural sources known as natural adhesive and another is synthetic adhesive.

- ❖ **Natural adhesive:** Adhesives of natural origin- such as animal, casein, soybean, starch and blood glues are still being used to bond wood in some plants and shops, but are being replaced more and more by synthetics (Vick, 1999).
- ❖ **Synthetic adhesive or Synthetic resin adhesive:** Synthetic adhesives are man-made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific woodworking requirements. Synthetic adhesives can be categorized into two groups, namely thermosetting adhesives and thermoplastic adhesives (*Natasa et al. 2011*).

a) **Thermosetting adhesives:** These types of adhesives are usually based on formaldehyde (UF), Phenol formaldehyde (PF), Resorcinol formaldehyde (RF), Phenol resorcinol formaldehyde (PRF), Melamine formaldehyde (MF), Melamine urea formaldehyde (MUF), isocyanate etc; resigns. Thermosetting polymers make excellent structural adhesives because they undergo irreversible chemical change, and on reheating, they do not soften and flow again (*Natasa et al. 2011*).

b) **Thermoplastic adhesives:** These are based on poly-vinyl acetate (PVAC). Thermoplastics are long-chain polymers that soften and flow on heating, and then harden again by cooling. They generally have less resistance to heat, moisture, and long-term static loading than do thermosetting polymers. Common wood adhesives that are based on thermoplastic polymers include polyvinyl acetate emulsions, elastomerics, contacts, hot-melts etc. (Vick, 1999).

- **Cement as binder for particleboard:** Although, above two types of adhesives are mainly used in the particleboard industries, but now-a-days cement (Portland) is also used as a binder for particleboard (Kavanagh, 2009).

2.3. General description of Polyethylene:

Polyethylene is created through the polymerization of ethylene (i.e, ethane)

2.3.1. Chemical Composition:

The ethylene molecule is C2H4 (CH2=CH2)

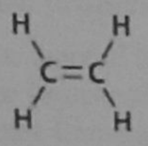

Fig: ethylene

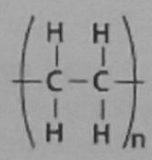

Fig: Polyethylene polymer

2.3.2. Properties:

The properties of polyethylene can be divided into mechanical, chemical, electrical, optical, and thermal properties

1. **Mechanical properties**

Polyethylene is of low strength, hardness and rigidity, but has a high ductility and impact strength as well as low friction. It shows strong creep under persistent force, which can be reduced by addition of short fibers. It feels waxy when touched.

2. **Thermal properties**

The usefulness of polyethylene is limited by its melting point of 80 °C (176 °F) (HDPE, types of low crystalline softens earlier). For common commercial grades of medium- and high-density polyethylene the melting point is typically in the range 120 to 180 °C (248 to 356 °F). The melting point for average, commercial, low-density polyethylene is typically 105 to 115 °C (221 to 239 °F). These temperatures vary strongly with the type of polyethylene.

3. **Chemical properties**

Most LDPE, MDPE, and HDPE grades have excellent chemical resistance, meaning they are not attacked by strong acids or strong bases, and are resistant to gentle oxidants and reducing agents. Crystalline samples do not dissolve at room temperature. Polyethylene (other than cross-linked polyethylene) usually can be dissolved at elevated temperatures in aromatic_hydrocarbons such as toluene or xylene, or in chlorinated solvents such as trichloroethane or Polyethylene absorbs almost no water. The gas and water vapor permeability (only polar gases) is lower than for most plastics; oxygen, carbon_dioxide and flavorings on the other hand can pass it easily.PE can become brittle when exposed to sunlight, carbon_black is usually used as a UV stabilizer.Polyethylene burns slowly with a blue flame having a yellow tip and gives off an odor of paraffin .

4. **Electrical properties**

Polyethylene is a good electrical_insulator. It offers good tracking resistance; however, it becomes easily electrostatically charged (which can be reduced by additions of graphite, carbon_black or antistatic agents).

5. **Optical properties**

Depending on thermal history and film thickness PE can vary between almost clear (transparent), milky-opaque (translucent) or opaque. LDPE thereby owns the greatest, LLDPE slightly less and HDPE the least transparency. Transparency is reduced by crystallites if they are larger than the wavelength of visible light

2.3.3: Manufacturing:

Melt processing of polyethylene can be achieve via extrusion and molding. Common extrusion methods including production of melt blown and spun bond fibers to form long rolls for future conversion into a wide range of useful products such as face masks, filters, diapers. The most common shaping technique is injection molding, which is use for parts such as cups, cutlery, vials. the related techniques of blow molding and injection stretch blow molding are also used which involve both extrusion and molding

3.Materials and Methods:

3.2 Flat-pressed WPC manufacturing using Polyethylene:

3.2.1: Selecting variables:

There are two types of variables. i.e. dependent and independent. In this study, temperature and pressure was the independent variables. Temperature was fixed at 190°C and pressure 5 N/mm2. On the other hand melting temperature, density and melt flow index of polyethylene is respectively 260°C, 1370 (Kg/m3) and 18.4 g/10. In order to avoid the degradation of wood components, pressing temperature 190°C was set below the melting temperature 260°C of PE (Polyethylene) Beside this, particle-plastic ration and pressing time are the dependent variables. This particle and plastic are quite difference in their nature, i.e. particle is hydrophilic and plastic is hydrophobic.

3.2.2 Collection of raw Materials:

Jute stick was collected from the local market of Khulna, Bangladesh and PE (Polyethylene) was also collected from the local market of Khulna for the manufacturing of Wood Plastic Composite Board.

3.2.3 Manufacturing place

The WPC board was manufactured at wood lab that is controlled under by Forestry and wood technology discipline, Khulna University, Khulna. All tests for its quality were also done there.

3.2.4 Preparation of raw Materials:

To make a good strength, smooth surfaces and equal swelling, manufacturing ideally using a heterogeneous material, no over-size particles, no splinters and no dust is needed. After collecting the raw material, a laboratory scale grinder was used to make particle of the jute stick. Clean consumer drinking water bottles which were collected locally and grind in a high speed grinder for getting the recycled PE powder.,

3.2.5 Screening Particles:

The particle were screened to remove smaller (0.5mm) with mesh no 35 and oversized (>2mm) particles mesh no 10 and screened to remove the impurities. The PE(Polythylene) powder was sieved by 35 mesh size sieve to remove the oversized particles.

3.2.6 Drying of screened particle:

After screening the particles of each type were inserted in to the oven for drying. The particle was then dried in an oven at 103 ± 2°C for 4 hours for a moisture content of 2% and PE (Polyethylene) powder was also dried at 103 ± 2°C for 4 hours for a moisture content of 3% or less with a laboratory oven.

3.2.7 Mixing of binder:

The addition of adhesive the plastic material that means PE (Polyethylene) was mixed with Jute stick by handshaking process then formed into a product (Hwang and Hsiung, 2000). It is a critical step for both product quality and production efficiency (Youngquist, 1999). In case of WPC board 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.

3.2.8 Mat Forming:

After mixing the particles of each type of ratio were formed into mat separately on the separate steel sheet. The mats of each type were formed manually. And the average mat thickness was about 5 times of the targeted board thickness (6 mm) for each type because PE (Polyethylene) has melting property. Mat is formed into 3-4 times and even 20 times thicker than the target board thickness, depending on the particle geometry and density of the raw material (Salehuddin, 1992 and Youngquist, 1999).

Fig: Mat Formation

3.2.9 Hot pressing:

After mat formation, a steel sheet was placed onto the mat (for each type) and then inserted manually into the hot press (each type separately) for pressing. After inserting the mat into the hot press, the pressure was raised manually by digital hydraulic hot press up to 5 MPa. he maximum pressing temperature, pressure, time and pressure holding time respectively were 190°C, 5 N/mm2, 25 minutes and 6 minutes. Lower temperature (190°C) compared to melting temperature (260°C) of the PE (Polyethylene) was set to avoid the degradation of the wood components. The press cycle consisted of three phases (Chen et al. 2006). First phase involved the manual pressing to reduce the mat height then second phase involved in shifting it to the electrically heated improvised hot press for hot pressing, and finally for cold pressing to facilitate the setting of thermoplastic resin.

3.2.10 CONDITIONING AND FINISHING

After stopping temperature the board was remained fixed for cooling or conditioning. The hot boards are removed from the press (or sawn across on continuous presses) and further conditioned to equilibrate board moisture content and to stabilize and fully cure the adhesives (AWPA, 2001). After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The board is trimmed to obtain the desired length and width and to square the edges. At least six replications of each type of WPC panels having 30 × 25 × 0.6 cm dimension were fabricated. The WPC panels were then trimmed and put into a conditioning room before testing for 48 hours

3.3 Specifications of Manufactured WPC Board

3.3.1. Table 3.3 Specifications of manufacturing WPC Board:

Dimensions (mm)	300 x 250x60
Thickness (mm)	9 (Average)
Layer	Single
Board Types	4
Replications	6(for each type)
Total board manufactured	12
Binder	PE

3.3.2 LABORATORY TESTS

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards were carried out respectively in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna, Khulna. The properties were tested according to the procedures defined in the American standard for particleboards (ANSI A208.1–1993) (NPA, 1993) as well as the Indian standard for particleboards (IS: 3087-1985) (Anon, 1985).

3.3.3 PREPARATION OF SAMPLES FOR TESTING

Three replications of each type of boards were manufactured as stated earlier. For testing physical properties, six samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same nine (9) samples and the Water Absorption, Thickness Swelling and Linear Expansion were determined on the other nine (9) samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of mechanical properties. The MOR and MOE were determined on the separate samples.

The dimension of samples for testing the physical properties was approximately (50 mm x 35 mm) and for testing the mechanical properties was approximately (180 mm x 35 mm).

3.4 Determination of physical properties

All the samples are cut into (50 mm x 35 mm) dimension for testing physical properties. The laboratory test for characterization of physical properties is carried out in the laboratory of Forestry and Wood 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 24 hour. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

3.4.1 DENSITY

Density of each sample was measured in the Wood Technology Laboratory of FWT Discipline of Khulna University, Khulna. Density was calculated with the following formula-

$$\rho = \frac{m}{v}$$ (Desch and Dinwoodie, 1996)

Where, ρ = Density in gm/cm^3; m = Mass of the sample in gm and v = Volume in cm^3.

3.4.2MOISTURE CONTENT

The moisture content was determined, from the differences in weights before and after the sample has been drying in the oven. Initial and final weight of the samples was measured by electric balance. It was calculated by the following formula-

$$MC\ (\%) = \frac{m_{\text{int}} - m_{od}}{m_{od}} \times 100 \qquad \text{(Desch and Dinwoodie, 1996)}$$

Where, MC = Moisture content (%), m_{int} = Initial mass of the sample (gm), m_{0d} = Oven-dry mass of the sample (gm).

3.4.3 WATER ABSORPTION

Water absorption is defined as the difference in weight before and after immersion in water and expressed in percentage. The water absorption was calculated by the following formula-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100 \qquad \text{(ASTM, 1997)}$$

Where, A_w =Water absorption (%), m_2 = The weight of the sample after (24 hr.) immersion in water (gm), m_1 = The weight of the sample before immersion in water (gm).

3.4.4 THICKNESS SWELLING

Thickness swelling was calculated by the following formula-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100 \qquad \text{(ASTM, 1997)}$$

Where,

G_t= Thickness swelling (%), t_2 = Thickness of sample after immersion (24 hr.) in water (mm), t_1 = Thickness of sample before immersion in water (mm).

3.4.5 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.

3.4.6 MODULUS OF RUPTURE (MOR)

Modulus of rupture (MOR) was measured with the Universal Testing Machine (UTM), model: WE-100, made by Time Group Inc. in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna.

The MOR was calculated from the following equation-

$MOR = \frac{3PL}{2bd^2}$ (Desch and Dinwoodie, 1996)

Where, *MOR* is the modulus of rupture in (N/mm^2), *P*= Load in N, *L*= Span length in (mm), *b*= width of test sample in (mm), *d*= Thickness of test sample in (mm).

3.4.7 MODULUS OF ELASTICITY (MOE)

The Modulus of elasticity (MOE) was also measured with the Universal Testing Machine (UTM) in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna. The modulus of elasticity (MOE) was calculated from the following equation-

$MOE = \frac{P'L^3}{4\Delta bd^3}$ (Desch and Dinwoodie, 1996)

Where, *MOE* is the modulus of elasticity in (N/mm^2), P' is the load in N at the limit of proportionality, *L* is the span length in (mm), Δ is the deflection in mm at the limit of proportionality, *b* is the width of sample in (mm), *d* is the thickness/depth of sample in (mm).

3.5 Analysis of Data:

All the data, produced during the laboratory tests for characterization of physical and mechanical properties of each type of particleboards, were analyzed by using Microsoft Office Excel 2007 and SAS (Statistical Analysis System) software. ANOVA (Analysis of Variance) and LSD (Least Significant Difference) were done to analyze the data.

4. Result & Discussion:

The results of different physical and mechanical properties that were found during different laboratory tests are delineated (with standard error bar) here. The study was conducted based on four different ratios FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40 for manufacturing Wood Plastic Composite (WPC) board. The abbreviations used in this chapter are PE,FS, CS,FRK,CRK are Polyethylene, Fine Shimul, Course Shimul, Fine Raj Koroi, Coarse Raj Koroi respectively.

4.1. Physical Properties:

4.1.1. Density:

Density is quantity that is used to describe the mass of a material per unit volume (Irle and Barbu, 2010). It has been found that the density of three different ratio (FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40, CRK:PE-60:40) of Wood Plastic Composite (WPC) board manufactured from Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) 939.904kg/m3, 835.822kg/m3 and 965.998kg/m3 and 881.517kg/m3 respectively. (Fig-4.1).the variation in density among the different types of WPC boards may be due to the variation in ratio of the different raw materials itself. From the following (Fig-4.1), we have seen that wood plastic ratio has impact on density. Density is gradually changing with the different species and particle size.

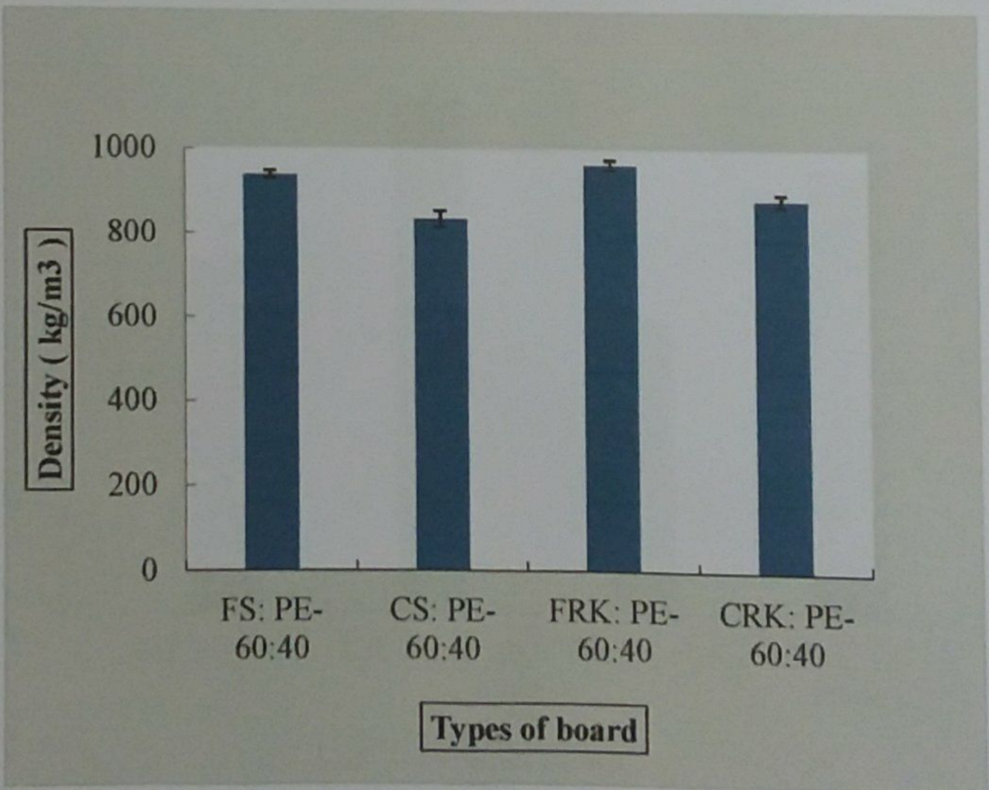

Fig. 4.1 Density of WPC board with different species and particle size

So we can say the same amount but different ratio of wood particle size and different type species may causes of different density in WPC board. From the analysis of variance (Table A-3.1), it has been observed that there was insignificant difference ($P > 0.05$) in density among the different types of species and wood particle size. That means alternative hypothesis accepted and null hypothesis rejected.

According to ANSI A208.1–1993 (NPA, 1993), all types of boards manufactured are fall into the low density (LD) grade (< 640 kg/m^3) and according to Indian Standard IS: 3087-1985 (Anon, 1985), the density of standard particleboard is 500 - 900 kg/m^3. But according to Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003) and German Standard DIN 68 761 (Verkor and Leduge, 1975), the density of standard particleboard is 640 kg/m^3 and 600 – 750 kg/m^3, respectively. The density of the four types of board follows the both type of standard.

4.1.2 Moisture Content:

Espert et al. (2003) stated that wood 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. Following (Fig. 4.2) demonstrated that with the increasing of wood-plastic ratio percentage, the MC content straightly decreases.

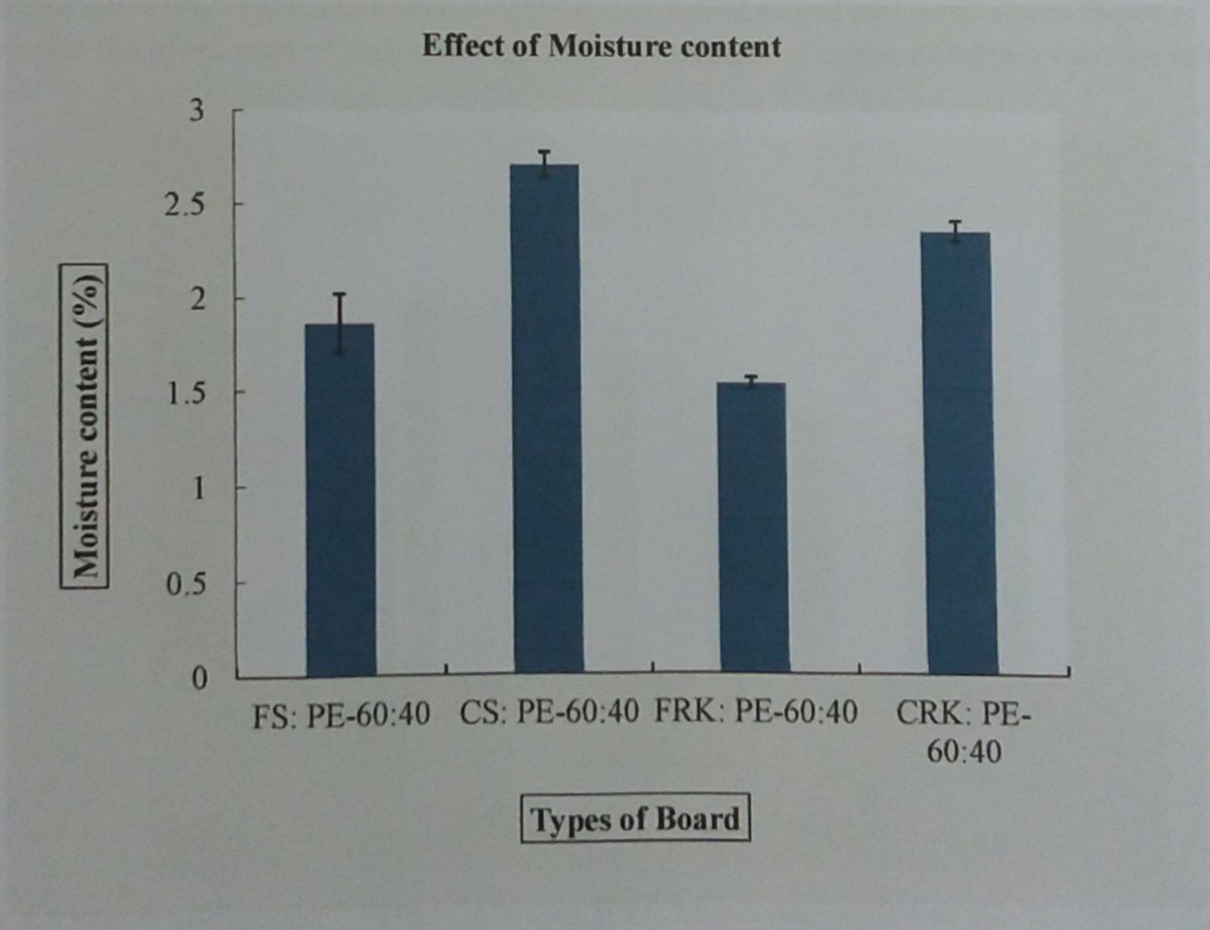

Fig. 4.2 Density of WPC board with different species and particle size

The moisture content of four different ratios (FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40) were 1.86%, 2.71% and 1.54% and 2.35% respectively (Fig. 4.2). The variation in moisture content in different types of boards may be due to the variation in ratio among different raw materials itself and also for the particle size. The moisture content ratio of wood particle and polyethylene CS:PE-60:40 was higher (2.71%) than that of other types of particles.

From the analysis of variance (Table A-3.3), it has been observed that there was significant difference ($P > 0.05$) in moisture content among the different types of WPC boards. That means alternative hypothesis accepted and null hypothesis rejected. The maximum moisture content in the standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975). But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the moisture content of standard particleboard is 5-8% (for 18 mm thick board) (The Laminex Group, 2003). So the moisture content% of the fourtypes of board below the level of standard of the both type of standard.

4.1.3 Water Absorption:

It was found that the absorption of water of four different ratios (FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40)of Wood Plastic Composite (WPC) board from Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) manufactured moisture content Figure (4.3) show that the lower ratio of plastic has the higher percentage of water absorption then the other ratios.

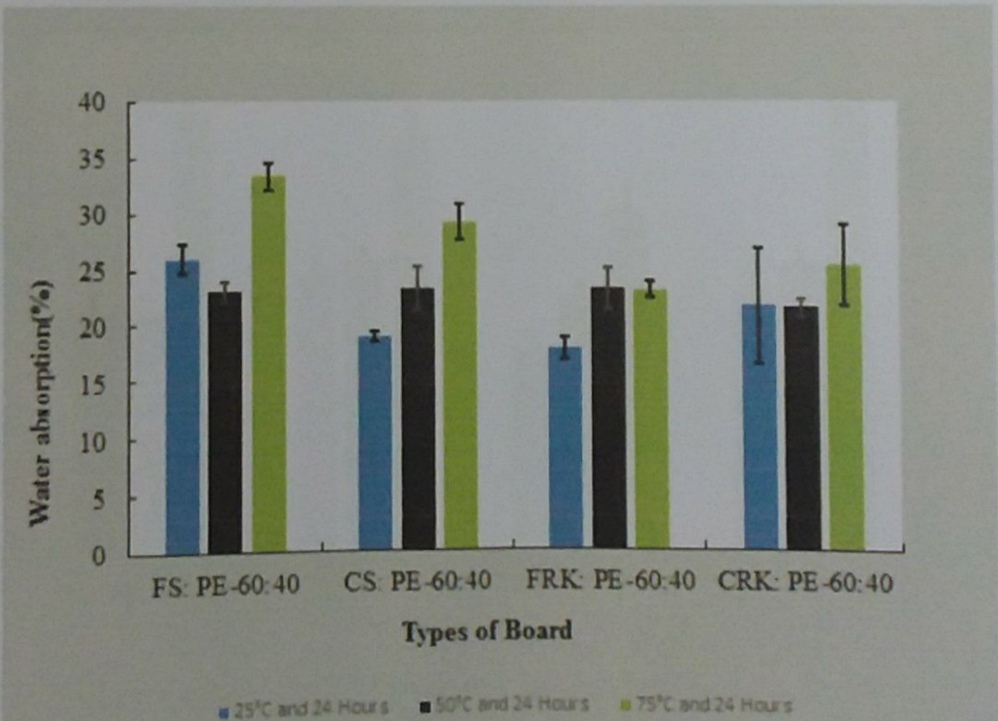

Fig.4.3 Water absorption% (after 24 hr.) of WPC board with different species and particle size

The causes behind this may be the hydrophilic nature of wood and hydrophobic nature of plastic. Also density is gradually increased with the increases plastic content in wood-plastic ratio. So decreases of plastic content may be the result of higher water absorption.

From the analysis of variance (Table A-3.5), it has been observed that there was insignificant difference ($P > 0.05$) in water absorption percentages among the different types of particle size of WPC boards that means alternative hypothesis accepted and there was significantly difference ($p < .05$) in water absorption among the different types of species that means null hypothesis accepted. (p<0.According to IS: 3087-1985 (Anon, 1985), the absorption of water by standard particleboard is 50% after 24 hours. The water absorption percentage by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) as well as Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int) (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975).

4.1.4 Thickness Swelling:

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. The variation in the thickness swelling among the different types of boards due to the variation in the amount of plastic contents in different boards.

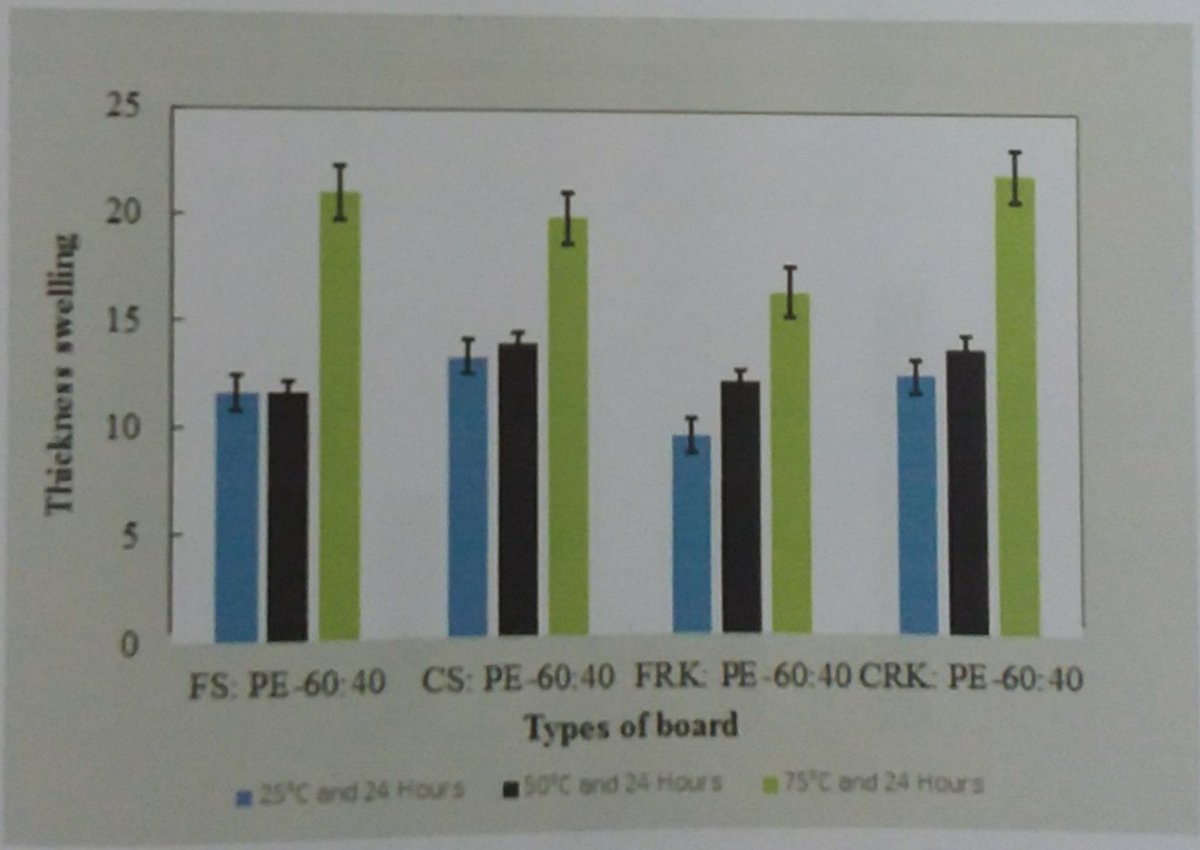

Fig.4.4 Thickness swelling % (after 24 hr.) of WPC board with different species and particle size

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. From the analysis of variance (Table A-3.7), it has been observed that there was significant difference ($P < 0.05$) in thickness swelling percentages among the different types of species. From the LSD (Least Significant Difference) analysis (Table A-3.8), it has been observed that there was insignificant ($P>0.05$) difference in thickness swelling percentages among the different types of particle size.

The thickness swelling percentage after 24 hours immersion in water by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975). But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the thickness swelling of standard particleboard is 15 % after 24 hours immersion in water (for 18 mm thick board) (The Laminex Group, 2003).

4.2 Mechanical Properties:

4.2.1 Modulus of Rupture (MOR):

The modulus of rupture (MOR) of four different ratios(FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40) of Wood Plastic Composite (WPC) board manufactured were found 20.6146 N/mm², 32.3414N/mm² , 25.1619 N/mm² and 38.494 N/mm² respectively(Fig. 4.6). It has been remarked from the Fig. (4.6) that the MOR of wood plastic board arrived at the highest value 38.494 N/mm² CRK:PE-60:40 ratio of wood particle and Polyethylene

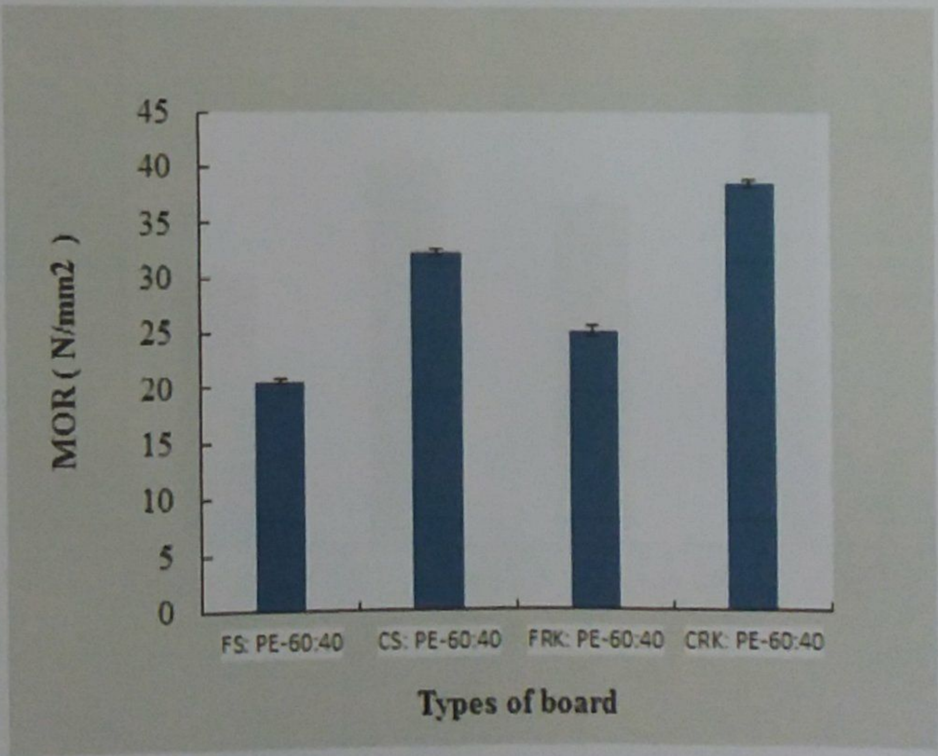

Fig. 4.5 Modulus of rupture (MOR) of WPC board with different species and particle size

On the other hand, as the ratio increases MOR of the boards are also increases. The highest strength of WPCs were measured when the lowest wood content is used and the strength decreased most severely when wood content increases (*Shao-Yuan et al. 2011*).

From the analysis of variance (Table A-3.11), it has been observed that there was highly significant difference ($P < 0.01$) in MOR among the different types of particleboards. According to ANSI A208.1–1993 (NPA, 1993), the MOR of standard particleboard is 16.5- 23.5 N/mm² for high density grade, 11.0- 16.5 N/mm² for medium density grade and 3.0- 5.0 N/mm² for low density grade. According to IS: 3087-1985 (Anon, 1985), the MOR of standard particleboard is 10.98 N/mm². But according to Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975), the MOR of standard particleboard is 16 N/mm² (for 18 mm thick board), 13.80 N/mm² and 17.65 N/mm², respectively.

4.2.2 Modulas of Elasticity (MOE):

Modulus of elasticity (MOE) of the four ratios were 1914.08N/mm², 2743.83 N/mm²,2406.35N/mm² and 3608.153N/mm² respectively found in four different ratios (FS:PE-60:40,CS:PE-60:40,FRK:PE-60:40,CRK:PE-60:40) of Wood Plastic Composite (WPC) board (Fig. 4.7).

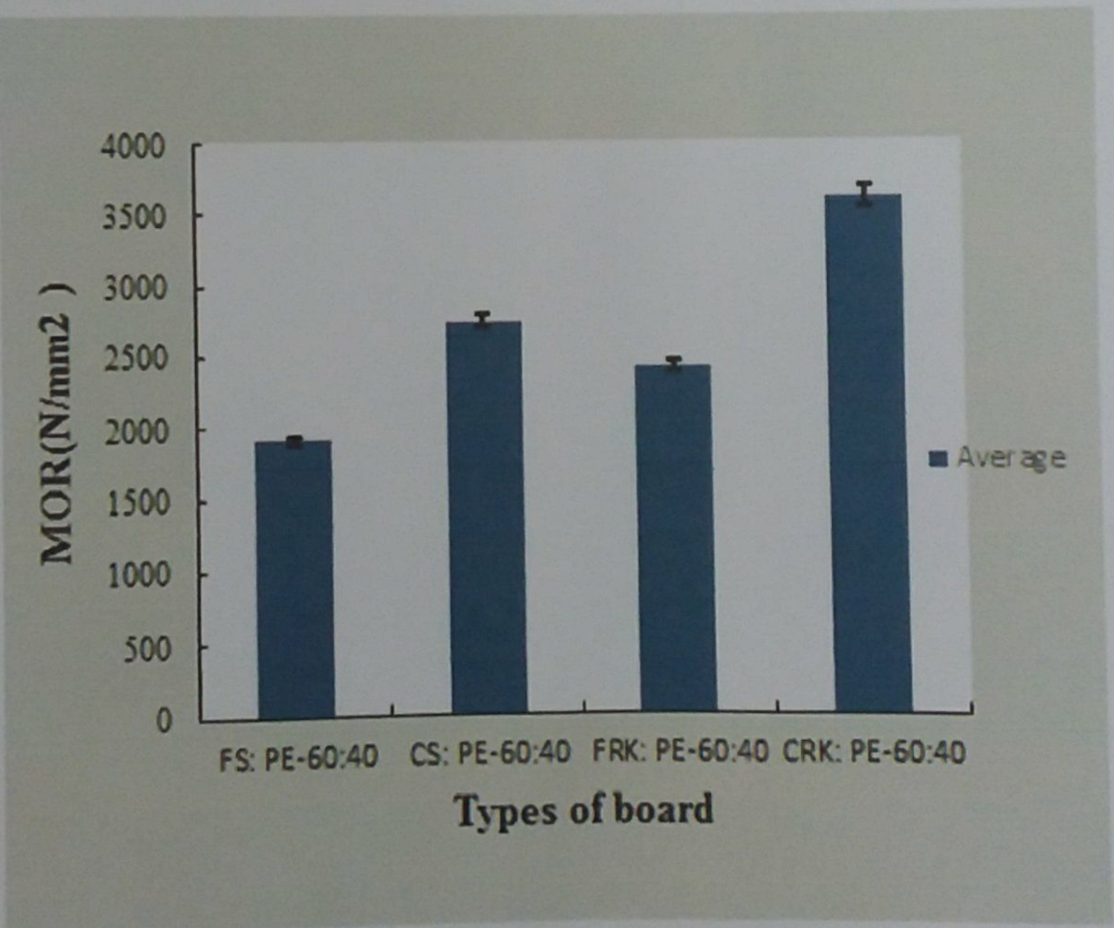

Fig. 4.6 Modulus of Elasticity (MOE) of WPC board with different species and particle size

The variation that was found in MOE among the different types of particleboards may be due to the same reasons for variation in MOR among the different types of particleboards. From the analysis of variance (Table A-3.13), it has been observed that there was highly significant difference ($P < 0.01$) in MOE among the different types of particle size and species.

5.Conclusion

The increasing demand of wood and wood products creates immense pressure on the limited forest resources of Bangladesh. Therefore, it is now especially important to utilize forest resources in more effective and economic ways. WPC board manufacturing industries are established to reduce the pressure on the solid wood. In this work, particles and fibres from Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) were used as wood particle in wood plastic composite (WPC) board manufacturing along with Polyethylene (PE) was used as binder used to make experimental WPC panels. WPC board manufacturing requires very poor or no management techniques or procedure. The planting method of Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) .tree is very simple and can be planted by direct branch. In the light of the preliminary results of this study both physical and mechanical properties of the samples were provided satisfactory results with the standard. If Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) are used commercially for manufacturing WPC board, it will be an appropriate alternate source of raw material for WPC board industries. In this situation, the government and WPC board industry owners may take initiatives for utilizing Shimul (*Bombax ceiba*) and Raj Koroi (*Albizia richardiana*) as an alternate source of raw material for manufacturing of WPC board in future.

6.References

Anon. 1982. Bangladesher Banna Sampod (Forest Resources in Bangladesh). Agriculture and Forest Division, Forest Department, Bangladesh, 22 pp.

Anon. 1985. Specification for wood particleboards (medium density) for general purposes (First revision). IS: 3087-1985, Indian Standard Institution, New Delhi, 19 pp.

Anon. 2006. Wikipedia. Online document, Retrieval with Opera version 9.64, retrieved on December 14, 2009. Web address: <http://en.wikipedia.org/wiki/Arecaceae>.

Anon. 2007. Particle board. Wikipedia. Online document, Retrieval with Opera version 9.64, retrieved on April 28, 2009. Web address: <http://en.wikipedia.org/wiki/Particle_board>.

Anon. 2008[a]. Waferboard. Wikipedia. Online document, Retrieval with Opera version 9.64, retrieved on October 30, 2009. Web address: <http://en.wikipedia.org/wiki/Waferboard>.

Anon. 2008[b]. Oriented strand board. Wikipedia. Online document, Retrieval with Opera version 9.64, retrieved on October 30, 2009. Web address: <http://en.wikipedia.org/wiki/Oriented_strand_board>.

ASTM. 1997. Standard methods for testing small clear specimens of timber. ASTM D143. West Conshohocken, PA: American Society for Testing and Materials.

AWPA (Australian Wood Panels Association). 2001. Manufacture. Australian Wood Panels Association Incorporated, Coolangatta Qld, pp. 1-6.AWPA (Australian Wood Panels Association). 2008. Product Range and Properties. Australian Wood Panels Association Incorporated. Online document, Retrieval with Opera version 9.64, retrieved on November 02, 2009. Web address: <http://www.woodpanels.org.au/productinfo/default.asp>.

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

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.

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.

Morton, J., and L. Rossi. "Current and Emerging Applications for Natural and Wood Fiber Composites." 7th International Conference on Woodfiber-Plastic Composites. Madison, WI: Forest Products Society, 2003.

Moslemi, A.A. 1985. Particleboard; (volume – 1: Materials & Volume – 2 Technology.)

Nadir A., Songklod J., Vallayuth F., Piyawade B., 2011. Effect of thermal-treatment of wood fibres on properties of flat-pressed wood plastic composites. Polymer Degradation and Stability 96 (2011) 818-822.

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.

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

NPA. 1993. Particleboard, ANSI A208.1–1993. Gaithersburg, MD: National Particleboard Association.

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.

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.

Appendix: Table of Data Analysis

TABLE A-1: ANOVA FOR DENSITY

Tests of Between-Subjects Effects

Dependent Variable: Density

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	61640.202[a]	3	20546.734	8.864	.001	.571
Intercept	19691814.828	1	19691814.828	8495.558	.000	.998
Species	7730.527	1	7730.527	3.335	.083	.143
PS	53333.347	1	53333.347	23.009	.00010981	.535
Species * PS	576.328	1	576.328	.249	.623	.012
Error	46357.910	20	2317.896			
Total	19799812.940	24				
Corrected Total	107998.112	23				

a. R Squared = .571 (Adjusted R Squared = .506)

TABLE A-2: ANOVA FOR MOISTURE CONTENT

Tests of Between-Subjects Effects

Dependent Variable: MC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.473[a]	3	1.824	102.697	.000
Intercept	103.323	1	103.323	5815.951	.000
Species	.387	1	.387	21.804	.000
PS	5.024	1	5.024	282.812	.000
Species * PS	.062	1	.062	3.474	.077
Error	.355	20	.018		
Total	109.151	24			
Corrected Total	5.829	23			

a. R Squared = .939 (Adjusted R Squared = .930)

TABLE A-3: ANOVA FOR WATER ABSORPTION

Tests of Between-Subjects Effects

Dependent Variable: Water Absorption

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	525.187[a]	3	175.062	3.299	.041
Intercept	6789.158	1	6789.158	127.944	.000
Species	276.394	1	276.394	5.209	.034
PS	16.613	1	16.613	.313	.582
Species * PS	232.180	1	232.180	4.376	.049
Error	1061.271	20	53.064		
Total	8375.616	24			
Corrected Total	1586.459	23			

a. R Squared = .331 (Adjusted R Squared = .231)

TABLE A-4: ANOVA FOR THICKNESS SWELLING

Tests of Between-Subjects Effects

Dependent Variable: Thickness Swelling

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	525.158[a]	3	175.053	3.299	.041
Intercept	6789.154	1	6789.154	127.946	.000
Species	276.377	1	276.377	5.209	.034
PS	16.614	1	16.614	.313	.582
Species * PS	232.167	1	232.167	4.375	.049
Error	1061.250	20	53.063		
Total	8375.563	24			
Corrected Total	1586.409	23			

a. R Squared = .331 (Adjusted R Squared = .231)

TABLE A-5: ANOVA FOR MOR

Tests of Between-Subjects Effects

Dependent Variable: MOR

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1098.425[a]	3	366.142	390.537	.000
Intercept	20704.499	1	20704.499	22083.984	.000
Species	151.921	1	151.921	162.043	.000
PS	942.619	1	942.619	1005.424	.000
Species * PS	3.884	1	3.884	4.143	.055
Error	18.751	20	.938		
Total	21821.674	24			
Corrected Total	1117.175	23			

a. R Squared = .983 (Adjusted R Squared = .981)

TABLE A-6: ANOVA FOR MOE

Tests of Between-Subjects Effects

Dependent Variable: MOE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8944922.837[a]	3	2981640.946	258.591	.000
Intercept	172189568.905	1	172189568.905	14933.602	.000
Species	2621691.253	1	2621691.253	227.373	.000
PS	6122226.208	1	6122226.208	530.966	.000
Species * PS	201005.376	1	201005.376	17.433	.000
Error	230606.874	20	11530.344		
Total	181365098.616	24			
Corrected Total	9175529.711	23			

a. R Squared = .975 (Adjusted R Squared = .971)