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USE OF EXPANDED POLYSTYRENE (EPS) BEADS AS A LOW DENSITY AGGREGATE TO REDUCE THE DENSITY OF CEMENT-BONDED PARTICLE BOARD (CBPB).

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DECLARATION

I, Suresh Kumar Nath, Student ID: MS-150513, hereby declare that this project thesis is based on my own research work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at other institutions.

Suresh Kumar Nath

Date: 19/11/17

Dedicated
To
My Beloved Parents

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ABSTRACT

Cement-bonded particleboard (CBPB) a very prominent product in wood industry because of some of its properties like, better stability, better thermal and sound insulation etc. than conventional particleboards. No synthetic adhesive is used for the production and different agricultural residues can be used as raw materials, which can reduce the pressure on forest timber. But one of the major problems of CBPB is its higher density (>1.3 g/cc). Thus, studies are being carried out to solve the problem. This study was designed in such way that low density jute stick particles and very low density expanded polystyrene (EPS) both were used as raw materials for further reduction of the CBPB. Moreover, as EPS reduce the mechanical properties significantly, jute fibers were integrated to know its effect on density, other physical as well as mechanical properties. It was found that gradual increase of EPS percentage as a raw material decreased the density significantly and lowest densities of 0.915 and .0921 were found for E-25 and EF-25 board types respectively. But, at the same time higher EPS was reducing the mechanical properties significantly until the jute fiber was added. Jute fiber integration significantly improved the mechanical properties to a satisfactory level. The results thus prove that, EPS can be integrated in CBPB to reduce the density and at the same time small amount of jute fiber can recover the hampered mechanicals of CBPB.

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1 Introduction

1.1 Background of the study

Cement-bonded composites are emerging as an important class of construction materials (Karade, 2011). They are made of a cementitious matrix and fibers or particles (Karade, 2010). The fibers could be wood fibers, natural fibers or synthetic fibers (Frybort *et al.*, 2008). The particles are generally obtained from wood or other agro-forestry wastes(Jorge *et al.*, 2004). Cement-bonded particle board (CBPB) are already used thoroughly in Europe, United States, Russia and S.E. Asia, mainly for roofs, floors and walls (Soares Del Menezzi *et al.*, 2007).

But there are problems regarding use of wood as a raw material for CBPB production (Väisänen *et al.*, 2016). Wood as a raw material contributes significantly in improving a nation's economic base, industrialization and comfort of its teeming population (Sotannde *et al.*, 2012). Globally, the demand for wood and wood-based panel products has been on the increase (Morsy, 2011). The high demand for wood and wood-based panel products has resulted in over exploitation and unregulated harvesting of trees in both the natural and plantation forest leading to recent interest in lesser known timber species (Sotannde *et al.*, 2012). This imbalance between wood consumption and sustainable supply will have serious economic, social and environmental implication (Sotannde *et al.*, 2012). In recent years, several research groups have been evaluating the suitability of different non-woody lignocellulosic materials and residues for the manufacture of CBPB including timber and agricultural processing residues (Chow, 1974; Sotannde *et al.*, 2012; Väisänen *et al.*, 2016), rice straw (Fernandez and Taja-on, 2002; Morsy, 2011), rice husk (Sarkar *et al.*, 2012), bamboo (Das *et al.*, 2012; Sukartana *et al.*, 2002), sisal (Ferreira *et al.*, 2017), jute (Ferreira *et al.*, 2017), kenaf (Amel *et al.*, 2014) *etc.*

CBPB possess countless advantages compared to panels produced with organic resins: high durability, good dimensional stability, acoustic and thermal insulation properties and low production cost (Frybort *et al.*, 2008; Jorge *et al.*, 2004; Karade, 2011; Soares Del Menezzi *et al.*, 2007). One of the major problems of CBPB is higher density than other lignocellulosic materials based composites (Frybort *et al.*, 2008). In CBPB large amounts of cement is utilized in comparison to particles (cement:particles ratio higher then 3:1), so the final product has a high density (>1.3 g/cc), because cement is denser than wood (Frybort *et al.*, 2008; Jorge *et al.*, 2004; Soares Del Menezzi *et al.*, 2007). These high-density boards are difficult to handle, cut, nail and transport (Zhou and Kamdem, 2002). Therefore it would be desirable to develop a low-density board composite using larger amounts of particles, reducing the cement: particles ratio, using low density materials *etc*.

Jute, which is a bio-degradable and environment friendly agricultural product cultivated abundantly throughout the world are used for commercial purposes (IJIRA, 2010). Jute stick and fiber both can be good reinforcing material for CBPB as these materials possess very low density (0.18 g/cc) and grater tensile strength (353 MPa) respectively (Ferreira *et al.*, 2017; IJIRA, 2010). Another very low density (0.01-0.05 g/cc) material expanded polystyrene (EPS) can also be incorporated in CBPB to reduce the density which has been studied frequently to get low density cement composites (Chen *et al.*, 2010; Dissanayake *et al.*, 2017; Ferrándiz-Mas *et al.*, 2016; Kan and Demirboğa, 2009; Laukaitis *et al.*, 2005; Wu *et al.*, 2015). Out of the various polymers currently available, polystyrene, because of its preferable physical, optical and electrical properties, has generated a considerable amount of interest in the scientific community (Gray, 2011). EPS beads are classified as an artificial ultra-lightweight aggregate with a non-absorbent, hydrophobic and closed cell nature and presently, are also commercially available worldwide (Chen *et al.*, 2010). EPS can also be recycled and reused from waste EPS products to maintain a cleaner environment (Dissanayake *et al.*, 2017; Ferrándiz-Mas *et al.*, 2016; Kan and Demirboğa, 2009).

Bangladesh, an agrarian country located in the Indian subcontinent, where a huge amount of jute is produced every year (IJIRA, 2010). The jute sticks produced after separating the fiber become a waste and most of the times possess no value, mainly used as fuel and sometimes left alone to decompose. Successful use of this low density agricultural residue in the production of CBPB would reduce the pressure on wood and at the same time might increase the economic value of jute. Till now no known study has been conducted to produce low density composite products by using jute and EPS. Thus, this study was designed to find a process to utilize this waste jute sticks in producing some low density CBPB by incorporating EPS foam as a much less dense aggregate. Ordinary Portland cement (OPC) would be used for its faster Initial setting time, lesser curing period and higher initial strength. EPS might lessen the mechanical performance of CBPB. Thus, jute fiber would be used to reinforce the material mechanically in limited scale as the time is limited. If become successful, this study might make a new innovation in the field of composite products.

1.2 Objectives of the study

Jute can be collected in enough quantity from local markets of Bangladesh to manufacture CBPB in industrial scale. EPS is being imported and used in industrial scale in Bangladesh. Ordinary Portland cement (OPC) is also readily available all over the country as world class cement is produced in Bangladesh. As, all the raw materials are available in huge quantity CBPB might have a good future in Bangladesh. This study might be the starting point for the development of such CBPB in Bangladesh. Thus, the specific objectives of this study are:

- To produce low density cement-bonded particle board (CBPB) using OPC, jute and EPS.
- To assess the physical and mechanical properties of the produced CBPB.

2 Literature review

2.1 General information about particleboard

A particleboard is a board (or sheet) constituted from fragments of wood and/or other lingo-cellulosic materials (chips, shavings, flakes, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. (Shrivastava, 1997). It may be classified as a panel product manufactured under pressure and heat from particles of wood or other lingo-cellulosic materials bonded entirely with a binder, generally a synthetic resin, to which other chemicals (e.g., fire retardant, fungicide, water retardant etc.) may be added to improve certain properties (Salehuddin, 1992).

2.1.1 Brief history and development of particleboard

Particleboards are not more than a few decades old production. Before particleboard, modern plywood, as an alternative to natural wood, was invented in the 19th century, but by the end of the 1940s there was not enough lumber around to manufacture plywood affordably. By that time particleboard was intended to be a replacement (Sheng *et al.*, 2004). But before that scarcity in raw materials of plywood, first efforts were made in the early 1920's for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. Then new techniques introduced in the 1930's in resin applications with the growing demand paved the way for the industrial production of particleboard in the early 1940's (Moslemi, 1985). The first commercial piece was produced during World War II at a factory in Bremen, Germany. It used waste material such as planer shavings, off-cuts or sawdust, hammer-milled into chips, and bound together with a phenolic resin. Today's particleboard manufacturer provides high-quality products that consumers require due to up gradation of manufacturing techniques (Moslemi, 1985; Sheng *et al.*, 2004).

2.2 General information about cement-bonded composite

Among several types of mineral-bonded composite boards cement-bonded is one. The main mineral bonded boards are listed in Figure 1, grouped according to binder type and particle or fiber size. Cement bonded composites combines the properties of two important materials: cement and any fibrous materials like wood or agricultural residues. It is a panel product made up of either strands, flakes, chips, particles or fibers of wood or some agricultural residues bonded with ordinary Portland cement (Eusebio, 2003). There is currently a renaissance in manufacturing of wood–cement composites around the world and in particular in the Asia–Pacific region. The successful substitution of asbestos fibers with wood fibers in cement sheeting, which arose as a result of pioneering research in Australia, has led to the rapid expansion of the wood-fiber cement industry in Australasia and North America. Accompanying the expansion of the industry has been a diversification of the products produced by the industry, and wood-fiber cement composites are now used in a host of applications including sidings, shingles, soffits, flooring (as ceramic tile backboards), skirting, pipes and architectural columns. (Evans, 2000).

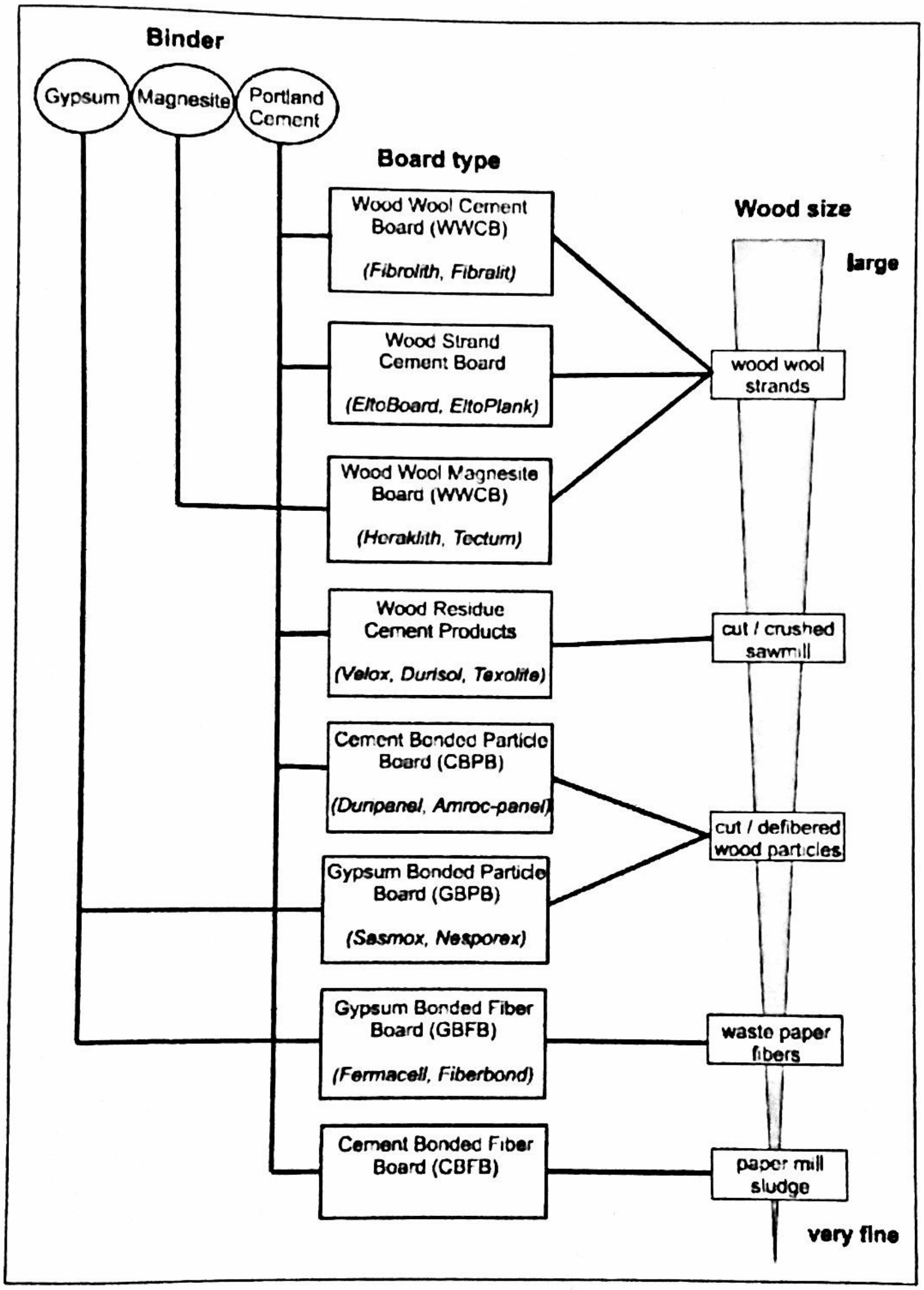

*Fig. 1. Overview of Mineral Bonded Wood Fiber, Particle and Strand Boards**

**Source: Van Elten, 1996*

2.2.1 Types of cement-bonded composite

There are three main types of wood-cement composites: 1) Wood-wool cement board (WWCB); 2) cement-bonded particleboard (CBPB); 3) wood-fiber reinforced cement composites (Eusebio, 2003; Evans, 2000).

The wood-wool cement board is made from debarked wood logs that have been stored for varying period of time to reduce the starch and sugar content of the wood, and then these logs are cross-cut into billets and these are shredded on a cutting machine to produce wood-wool. The post-harvest storage of raw materials has positive effect on mechanical properties (Eusebio, 2003; Evans, 2000; Ma *et al.*, 2002). Typical wood-wool strands used in the manufacture are approximately 3 mm wide and 0.5 mm thick with length up to 40-50 cm. Semple and Evans (2000) studied the effect of heartwood on mechanical properties of wood-wool cement boards and found that the inhibitor of heartwood would affect the cement hydration. Therefore, they suggest use young tree less than 12-15 years, which will contain little or no heartwood.

Prior to producing cement-bonded particleboard, debarked logs are stored for at least 2-3 months to reduce the moisture and sugar content. Similar to conventional particleboard, logs are processed to produce chips approximately 10-30 mm in length and 0.2-0.3 mm in thickness, which are further reduced in size using knife ring flakers and hammer mills. The resulting flakes are screened into three classes; fine, standard and coarse flakes. Fines are used for the board surface and standard-size flakes are used for the core of boards. Coarse flakes are returned for further reduction in size. Wood flakes are mixed with Portland cement and water in different ratio by weight (Evans, 2000).

Two categories of cement-bonded wood composite panels were suggested and fabricated. The first category was manufactured using ribbon-like wood particles called excelsior, which can be produced from low-quality forest thinnings. The second category used a varied particle geometry produced by grinding wood waste in a commercial tub grinder. Variables included particle geometry, chromated copper arsenate (CCA) treatment, wood species, method of panel formation, and composite density (Ma *et al.*, 2002). Furthermore, Ma *et al.* (2000) studied the relationship between hydration energy released of manufacture and mechanical properties of cement-bonded boards, and indicated that the total energy release is a quick way to determine suitable mixture of cement, addictive, and fibers. In addition, orientation of strands can improve the strength properties of cement-bonded boards (Ma *et al.*, 2002).

Wood- fiber reinforced cement composites are made from wood fiber, sand, cement, and aluminium trihydrate in different ratio by weight. Wood fibers, usually obtained from softwood chemical (kraft) pulp, act as a reinforcing agent in the boards, a role previously played by asbestos. The cement, fibers, sand and additives are combined in the different proportions and diluted to form slurry with a solids content of 10% (Evans, 2000).

2.3 General information about CBPB

2.3.1 Brief history and development of CBPB

In 1977 my company built its first plant for the production of CBPB. However, this concerned a relative low density board with a brickwork-like embossed and painted surface, used for external applications. The plant was installed near Dortmund, Germany. The embossing was obtained by pressing or milling. Mainly for the reason that these panels, produced in wooden moulds, were to small and the public in Germany disliked the sometimes visible joints between the boards, no further plants for this type of boards were built again. The panels at the houses built at that time however are still in perfect shape after more than 20 years, being repainted with synthetic paint only once (Van Elten, 1996).

In the eighties, when the high density and larger size CBPB panels, developed in Switzerland, got accepted in the market, my company built and supplied some large CBPB plants to the former Soviet Union. These plants were already equipped with the very successful mechanical distributing machines instead of the usual air supported distributing machines (Evans, 2000; Van Elten, 1996). In 1992 the owner of the Amroc/Zehoma CBPB plant in Magdeburg, Germany, demanded quotes for renovation of his CBPB plant because of complaints about board quality and thickness tolerances. Eltomation (Netherlands) developed and built a new mechanical distributing machine to produce CBPB boards with extremely low thickness variations (Van Elten, 1996).

2.3.2 Properties of CBPB

In cement bonded board technology, many parameters greatly affect board properties. Some of these are: material (wood/cement, agri-wastes/cement) ratio; water/cement ratio; type of wood/agri-wastes; cement setting accelerators and others (Chang, 2006). Eusebio (2003) indicated that hydration temperature was drastically reduced, hydration time was prolonged, and compressive strength was reduced as cement/wood ratio decreased. Some paper evaluated the effects of variability in wood strand dimensions, mechanical properties, and orientation on the engineering properties of cement excelsior board. Results suggest that variability in strand mechanical properties can significantly lower composite tensile and compressive strengths, while composite stiffness is not affected. Furthermore, strand alignment lead to increase the strength and stiffness in the direction of alignment (Chang, 2006).

Cement-bonded particleboard as a composite of wood chips and reacted Portland cement is dimensionally unstable in service in the presence of changes in relative humidity. One solution to this deficiency is the application of surface coatings to reduce its magnitude (Van Elten, 1996). Low and high density cement-bonded particleboards made conventionally and with carbon dioxide injection were tested against white and brown rot fungi. There was no measurable wood degradation (weight loss) which shows that cement-bonded particleboard is suitable for use in tropical countries where moisture is wood's greatest enemy (Jorge *et al.*, 2004; Onuaguluchi and Banthia, 2016). Chang (2006) studied the resistance to termite and point that these boards resist not only the decay caused by fungi, but also attack by termites.

2.3.3 Market opportunities of CBPB

Being suitable for all climatic conditions, highly fire resistant and impervious to termites, vermin and mold, CBPB is a very versatile building material. In Europe on the continent it is mainly applied as fire resistant partitioning, outside wall cladding, floor units and for permanent shuttering systems. In Hungary also for wall and roofing shingles and prefabricated housing. In the UK mainly for internal wall claddings as ceiling boards and for flooring with built-in heating systems. In Japan several plants are producing embossed and painted panels for cladding of outside walls (Van Elten, 1996).

Cement bonded board has gained favor throughout the industry due to its extended applications compared to plywood, resin-bonded particleboard and other allied products (Eusebio 2003). Extensive studies on the expansion of raw material base have been done thereby demonstrating the feasibility of producing CBB using local wood species, some agricultural wastes and even industrial residues (Eusebio, 2003; Van Elten, 1996).

The potential markets for these products are significant. Cement-bonded particleboard manufacturers do not presently use wood waste feedstock, but have expressed interest in using this resource. Slab and block products have the greatest potential for integrating wood waste feedstock. Satisfying the cement composite manufacturer's specifications and product quality expectations are critical to sustaining the captured market share (Van Elten, 1996). Cement bonded board has been found to be a good substitute for concrete hollow blocks, plywood, particleboard and other resin bonded boards. It is a very versatile material that can be used as ceiling, partition wall, exterior wall, flooring, eaves, cladding and even roofing provided that proper coating is applied. However, the most common application of cement bonded boards in the Philippines today is for wall and ceiling construction (Chang, 2006; Eusebio, 2003). Since the strength properties of cement bonded boards, particularly wood-wool cement boards, are not suitable for load-bearing elements, it is often used with framing materials like wood and steel section (Chang, 2006)

Some carpenters are hesitant to use the product while others still prefer plywood, concrete hollow blocks or other traditional materials. To augment the market, cement bonded board producers and distributors may prepare a company brochure that would clearly explain product application and construction system (Eusebio, 2003).

2.4 Raw materials for the production of CBPB

2.4.1 Ordinary Portland cement (OPC)

Ordinary Portland cement is a widely applied mineral binder for wood-wool cement composites. Based on the requirements of the board such as quick strength development and later an expectable mechanical strength. This cement is characterized as a high-quality binder, allowing fast hydration, and acceptable early and late mechanical properties (Taylor, 1997). Hydration is the result of a chemical reaction that occurs between water and the chemical compounds present in Portland cement. Portland cement is predominately composed of two calcium silicates which account for 70 % to 80 % of the cement. The common composition is summarized in Table 1 (Taylor, 1997).

*Table 1. Typical composition of ordinary Portland cement**

Chemical Name	Chemical Formula	Shorthand Notation	Weight Percent
Tricalcium silicate	$3CaO.SiO_2$	C_3S	50
Dicalcium silicate	$2CaO.SiO_2$	C_2S	25
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	12
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	8
Calcium sulfate dihydrate (gypsum)	$CaSO_4.2H_2O$	$C\underline{S}H_2$	3.5

**Source: Taylor, 1997*

The hydration characteristics of the cement compounds are summarized in Table 2 (Mindess *et al.*, 2003).

*Table 2. Characteristics of hydration of the cement compounds**

Compounds	Reaction Rate	Amount of Heat Liberated	Contribution to Cement	
			Strength	Heat Liberation
C_3S	Moderate	Moderate	High	High
C_2S	Slow	Low	Low initially, high later	Low
$C_3A + CSH_2$	Fast	Very High	Low	Very high
$C_4AF + CSH_2$	Moderate	Moderate	Low	Moderate

**Source: Mindess, Young and Darwin, 2003*

2.4.2 Reinforcement materials

2.4.2.1 Lignocellulosic materials

Lignocellulosic materials are obtained from wood and natural plants. They are composed of lignin and cellulosic compounds as main chemical constituents. Large amounts of these wastes are generated around the globe from various human activities. In developing countries the growth of industries based on agro-forestry products has accelerated the generation of wastes like rice husk and straw, wheat straw, bagasse, oil palm strands, hazel nuts and saw dust (Karade, 2010).

Woody materials

Woody Materials, Planner 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 dust. Logging residues, such as short logs, broken logs, crocked logs, small tree tops and branches, forest thinning, etc. and Bark (Salehuddin, 1992).

Non woody materials

Jute sticks, bagasse, bamboo, cotton stalks, flax shaves, cereal straw, almost any agriculture residue (such as husks, coconut coir etc.) after suitable treatment (Frybort *et al.*, 2008; Jorge *et al.*, 2004; Onuaguluchi and Banthia, 2016).

2.4.2.2 Others

Plastic, glass, feather etc. are used as a reinforcing material to produce cement bonded board. Waste chicken feather is used as reinforcement in cement-bonded composites (Karade, 2011). Polyethylene terephthalate (PET) is one of the most extensively used plastics in the world in beverage containers and other products. It is used for producing cement bonded plastic board (Chang, 2006). Further wood-plastic cement board is a famous board like wood-wool cement board. EPS foam is being used in producing lightweight concrete. This EPS might be a possible material to produce very low density CBPB (Chen *et al.*, 2010; Dissanayake *et al.*, 2017).

2.5 Advanced strategies for CBPB density reduction

The various strategies applied for panel weight reduction are much dependent on the final panel application. Thus, it is hard to generalize the selection criteria for weight reduction. Nevertheless, all of the strategies used for the reduction of panel density during recent decades can be segregated in two major groups; technology and materials.

Less compaction of the wood-furnish mat and hollow-tube profile fabrication of the panel (extruded boards) are the two technological methods for panel weight reduction which have found wide application in industrial practice. There have also been several attempts in the field of material selection used to produce light panels, e.g. by using low density wood species, annual or perennial plants (agriculture residues like maize, sunflower, hemp and etc), mixing of polymer beads (e.g. EPS) or starch granulates in the core and foamed adhesives (Ross, 2010). To create low-density spaces between the particles while maintaining the inter-particle connection foamed adhesives were used. The density reductions which can be achieved with most of these techniques are about 150 to 200 kg/m^3. It is worth to mention that today the density of particleboard is approximately 100 kg/m^3 lower than 20 years ago (Shalbafan, 2013). But, nevertheless, these techniques all have certain restrictions or disadvantages that require resolution (Shalbafan, 2013). In brief;

- Remarkable decline of mechanical properties what makes many lightweight panels unsuitable for applications requiring load bearing capacity
- Limitations to the surface finishing and post-forming
- Enforcing companies to have more varied stocks of raw materials and also requiring special production technologies and more training for their staff which increases the complexity of the manufacturing process

- The need for using special or more different binders due to the lower bonding strength of the alternative materials which increases the production cost.

2.5.1 Expanded polystyrene (EPS)

Expanded polystyrene (EPS) is a low-density, inert, hydrocarbon thermoplastic that is stable in the presence of most chemicals with the exception of concentrated acids, organic solvents and saturated aliphatic compounds. It is commonly used in a variety of applications because of its low density, high thermal insulation, moisture resistance, durability, acoustic absorption and low thermal conductivity. The amount of waste EPS is increasing due to increasing use in thermal and acoustic insulation, packaging, and reusing and storing food (Ferrándiz-Mas *et al.*, 2016; Kan and Demirboğa, 2009).

Unmodified EPS foams have a cellular microstructure with closed cell membranes made of expandable polystyrene (PS) and its density is typically less than 50 kg/m3. EPS is currently used as a packaging or insulating material in various industrial fields in the world. A large quantity of EPS is consumed, and is disposed as a waste. On the other hand, it is well known that the waste EPS has caused many environmental problems, especially water and land pollution, because it cannot be decomposed in nature (Kan and Demirboğa, 2009).

As an industry that has a high consumption of natural resources, the use of either recycled building demolition waste or any other waste material is becoming attractive. Expanded polystyrene (EPS) is one such material which is used in substantial quantities as a packaging material or as an insulating material. EPS has a very low density. An individual bead of EPS would be approximately spherical and contains only about 2% of polystyrene and about 98% of air. Once expanded, the beads would not absorb water and hence can be used as an ultra-light aggregate to obtain a light weight foam concrete. This has been successfully used to manufacture a wall panel that can be used as a partition material in multi-storey buildings or as a walling material in a single story construction (Dissanayake *et al.*, 2017).

2.6 Applications of CBPB

Fig. 2. Applications of CBPB (a) Embossed and painted CBPB for wall claddings, (b) Imitation Roofing Shakes of embossed and painted CBPB, (c) CBPB hollow wall panel, (d) Installation of the CBPB prefabricated floor units

2.6.1 Waste Management

To lessen the measure of wasted material a few stages are taken to avoid and re-utilize waste materials. New material from the finishes of the cauls at the caul quickening station, from the new board weight checking station and from the board stretching machine is sustained back to the blending territory and re-utilized. Pretrimmed material from 8 hours cured board is likewise re-utilized in the wake of refining, putting away and dosing. Up to 5% of this moderately new material might be added to the crisp blend in the blender without damage to the nature of the boards. Only a little amount of final trimmed-off material after drying has to be dumped (Van Elten, 1996).

2.6.2 Embossed surfaces

Not new, but rather still not broadly known are CBPB boards with decorated and covered surfaces in different setups like brickwork, wood grain or normal stone. Particularly in Japan these boards are exceptionally fruitful. Over 90% of the Japanese CBPB boards have a decorated and covered surface and are utilized for outside divider claddings. In view of the achievement in Japan, a few organizations in different nations are presently trying the market for these boards. The surfaces are normally rolled or shower painted in the coveted hues for which these days' different appropriate paints and coatings are accessible. The profiled molds (cauls) of fiber strengthened hard plastics with decorated surfaces are so solid and solid that they can supplant the ordinary steel caul, however once in each 5 to 10 boards an additional steel caul might be included for additional firmness (Frybort *et al.*, 2008; Van Elten, 1996).

2.6.3 Shingles

Likewise not new but rather extremely fascinating is the advancement of CBPB shingles. In Hungary utilizations of painted and unpainted shingles on dividers and rooftops are normal, however of exceptional intrigue the rooftop and divider shingles are created in a few states in western USA. Most likely the famous shrubbery fires in California and Sidney, Australia and the impact of insurance agencies help to advance these pleasant looking and inflammable shingles in the market (Jorge *et al.*, 2004; Van Elten, 1996).

2.6.4 Prefabricated wall and floor panels

Eltomation (Netherlands) is associated with the improvement of a plant for the creation of vast empty CBPB divider and floor boards with a general thickness of 15 to 30 cm, a divider stature up to 280 cm and a length up to 600 cm. Given the confounded molds with expandable water powered retractable bodies and the extremely unique press a CO_2 solidifying process is connected. With this procedure just a couple of molds are required. About at regular intervals one huge board can be created (Van Elten, 1996).

2.6.5 Permanent shuttering of concrete

Extremely intriguing is the effective use of vast size pre-assembled divider and floor components gathered of CBPB boards on the computer worked DUO-TEC mechanical production system. The computer program is all the while made by the engineer while planning the building. In the meantime all estimation work is finished by computer. The components comprise of CBPB boards, dispersed with metal or high malleable plastic spacers and have the required interior fortifications introduced. Every component is definitely sliced to the correct measurements at the industrial facility, including openings for links, channels, conduits, entryways and windows. On location the prefab components just must be introduced and loaded with concrete, making a solid development (Van Elten, 1996).

3 Materials and methods

3.1 Raw materials collection and preparation

Ordinary Portland cement (OPC) was bought from local market, stored in air tight pack till the time it was used.

Jute sticks and jute fiber were collected from nearby villages and markets of Khulna district and processed in the Wood Processing laboratory of Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh. The sticks were about 1-2m long and 5-10mm in diameter. The small branches and crown portion were removed by branch cutter. Then the jute sticks were kept under open sun for 2 weeks for drying. After that the narrow sticks were cut into small pieces by circular saw to feed into the chipper. Chipping of the jute sticks were done in the Wood Processing laboratory of Forestry and Wood Technology Discipline, Khulna University using a conventional chipper machine. Sieves of diameters 2.00mm and 1.00mm were used to obtain the jute stick particles which passes through the 2mm mesh and was retained by the 1mm mesh. Then the particles were spread out in rows 2 to 4 inches deep under ambient room conditions (approx. 25°C and 50% RH) until an average equilibrium moisture content (EMC) of 9% (oven-dry basis) was realized.

Jute fibers were cut into smaller size having average length of 2-3mm. The jute fibers were also dried under ambient room conditions (approx. 25°C and 50% RH) until an average equilibrium moisture content (EMC) of 9% (oven-dry basis) was realized.

EPS beads were collected from local market, which are industrially used to manufacture cork sheet. The beads were also screened through sieves having diameters of 2.00mm and 1.00mm.

Distilled water in specific ratio with cement was used as the curing agent of OPC.

3.1 Treatments used for the production of CBPB

All the boards were produced in the Wood Processing laboratory of Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh. A constant ration of cement, reinforcement particles and water (2.2:1:1.1 (w/w/w)) was followed for the manufacturing of all types of boards. Manufacturing conditions of all the produced boards are listed in Table 3. First board was produced using jute stick particles as the only reinforcing material. Then the amount (weight basis) of jute stick particles were gradually replaced with EPS beads. At last some boards were produced by replacing 5% of the jute particles with jute fiber.

Table 3. List of different types of produced CBPBs

Types of Boards	Shorthand Notation	Percentage of Jute Stick Particles Retained and Replaced With EPS and Jute Fiber		
		Jute Particles (%)	EPS (%)	Jute Fiber (%)
1	Control	100	0	0
2	E-05	95	5	0
3	E-10	90	10	0
4	E-15	85	15	0
5	E-20	80	20	0
6	E-25	75	25	0
8	EF-25	70	25	5

3.2 Particleboard manufacturing

The particleboards were produced at the Wood Processing laboratory of Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh. All the raw materials (OPC, jute stick particles, EPS beads, jute fiver and water) were mixed according to the types of boards in a rotary drum blender for 6 minutes for producing a homogenous mixture. At first cement and jute fibers were charged into the blender (when applicable). Then a paste was prepared by adding and blending the water. Then EPS beads were blended and at last jute stick particles were added and blended for about 6 minutes to get a uniform mixture of all the components. The mixture was placed in aluminium caul plate using a forming box to form standardized mat. During heating and pressing the mat, aluminium foil was used to avoid the direct contact between the board surface and metal plates. Pressing was completed in a single phase, a cold press having pressure of 5MPa was applied for a period of 24 hours to let the OPC set completely (Eusebio, 2003). The boards were placed at room temperature for 30 days. Water was sprayed frequently for proper curing of the boards (Nagadomi *et al.*, 1996). At least three replication of each type of board were performed to produce boards having dimension of 35 × 25 × .7cm approximately. The manufactured boards were trimmed and put into a conditioning room for 24 hours before testing of properties.

3.3 Determination of physical and mechanical properties

The laboratory tests of physical properties were done in the Wood Products laboratory of Forestry and Wood Technology Discipline of Khulna University, Bangladesh while mechanical properties were carried in the Laboratory of Akij Particle Board Mills Ltd., Manikgonj, Bangladesh. The Malaysian standard 'Specification For Wood Cement Boards', MS 934:1986 was followed to evaluate the both physical and mechanical properties.

3.3.1 Modulus of rupture (MOR)

The MOR was calculated by Equation 1.

$$MOR = \frac{3PL}{2bd^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 1$$

Where, MOR = the modulus of rupture (N/mm^2), P = load (N), L = span length (mm), b = width of test sample (mm), d = Thickness of test sample (mm).

3.3.2 Modulus of elasticity (MOE)

The MOE was calculated by Equation 2.

$$MOE = \frac{P'L^3}{4\Delta bd^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 2$$

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

3.4 Analysis of data

All the data, obtained during the laboratory tests for characterization of physical and mechanical properties of each type of particleboards were analyzed by using Microsoft Office Excel 2016 (USA) and Minitab 17 (USA). ANOVA (Analysis of Variance) and Tukey's HSD (honest significant difference) test were conducted to analyze the data ($\alpha \leq 0.05$).

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4 Results and discussion

4.1 Physical properties of the particleboards

The physical properties of board density, water absorption after 2 (WA_2) and 24 hours (WA_24) of immersion in water and thickness swelling (TS) after 2 (TS_2) and 24 hours (TS_24) of immersion were studied at 95% significance level. All of the properties are summarized in Table 4.

Table 4. Summary of the physical properties of the produced CBPBs

Types of Boards	Types of Properties				
	Density (g/cc)	WA_2 (%)	WA_24 (%)	TS_2 (%)	TS_24 (%)
Control	1.321	16.96	24.38	1.97	2.52
E-05	1.279	15.81	22.64	2.13	3.45
E-10	1.233	16.77	22.59	2.34	3.73
E-15	1.107	14.92	22.08	2.56	3.87
E-20	1.029	12.60	20.42	2.72	3.99
E-25	0.915	12.26	19.39	3.01	4.07
EF-25	0.921	10.43	18.33	2.27	3.71

4.1.1 Density

Mean values of CBPB densities are shown in Figure 3. From the result it was observed that there was significant difference among the densities obtained from different treatments (df=6, F=126.6, $P<0.05$).

Density of boards E-25 and EF-25 were the lowest. This might occurred because of higher EPS content, and both boards had same densities because of same percentage of EPS and the small amount of jute fibers might not have any effect on the final density. Density decreased with the increase of the percentage of EPS content. Higher percentage of EPS beads might have helped in this reduction by adding more and more low density aggregates.

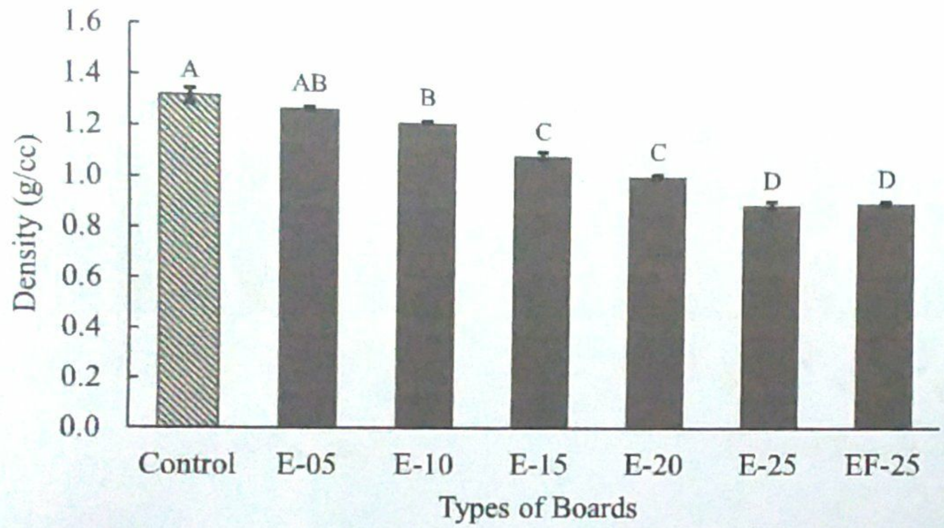

Fig. 3. Density of different types of boards

Das *et al.* (2012) produced cement-bonded board from bamboo wastage chips and cement, using different mixing ratio. They found densities from 1.48 to 1.8 g/cc after a cold press for 24 hours. All the densities found in this study are lower than this stated study.

Ghosh *et al.* (2015) found densities ranging from 1.00 to 1.07 from cement-bonded boards produced using *Areca catechu* stem particles. E-25 and EF-25 both boards produced in this study have lower density than the stated study.

4.1.2 Water absorption (WA)

Variation of the mean values of water absorption (%) after 2 hours (WA_2) and 24 hours of immersion (WA_24) in water is shown in Figure 4.

Water absorption percentage gradually decreased with the increased percentage of EPS for both 2 hours (WA_2, df=6, F=14, $P<0.05$) and 24 hours (WA_24, df=6, F=11, $P<0.05$) of immersion in water. This might have happened because of the water repellent property of EPS. As the percentage of EPS increased, the water absorption of the CBP boards decreased. This fact leads to conclude that EPS have positive impact on the water absorbing property of CBPB.

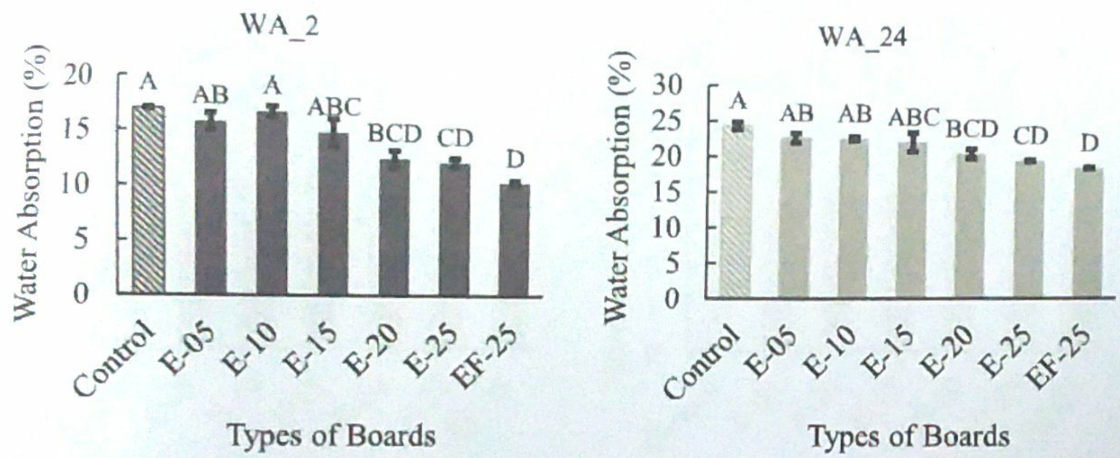

Fig. 4. Water absorption (%) of the boards after 2 (WA_2) and 24 (WA_24) hours of immersion in water.

Das *et al.* (2012) produced cement-bonded board from bamboo wastage chips and cement, using different mixing ratio. They found WA_24 values from 12.35 to 17.00% after a cold press for 24 hours. Most of the results found in this study are similar to the results of the stated study.

Ghosh *et al.* (2015) found WA_24 values ranging from 22.56 to 32.50% from cement-bonded boards produced using *Areca catechu* stem particles. E-25 and EF-25 both boards produced in this study have lower density than the stated study. Almost all of the results found in this study are lower than the results found in the stated study.

4.1.3 Thickness swelling (TS)

Variation of the mean values of thickness swelling (%) after 2 hours (TS_2) and 24 hours of immersion (TS_24) in water is shown in Figure 5.

Thickness swelling percentage gradually decreased with the increased percentage of EPS for both 2 (TS_2, df=6, F=23, P<0.05) and 24 hours (TS_24, df=6, F=80, P<0.05) of immersion in water. This might have happened because of the weaker bonding between cement and EPS. As the percentage of EPS increased, the thickness of the CBP boards increased. But the property improved in EF-25 board, may be because of the bonding improvement caused by jute fibers. This fact leads to conclude that EPS solely have negative impact on the water absorbing property of CBPB but jute fiber integration can significantly improve the property.

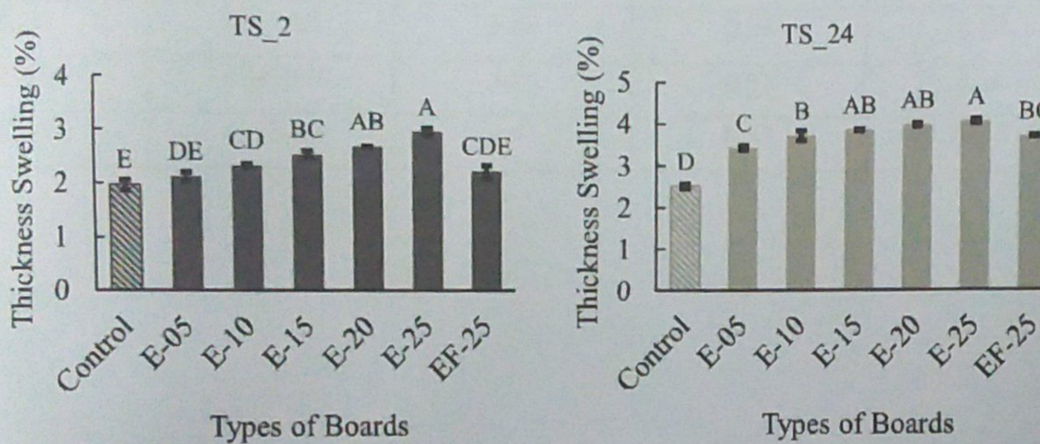

Fig. 5. Thickness swelling (%) of the boards after 2 (TS_2) and 24 (TS_24) hours of immersion in water.

Ghosh *et al.* (2015) found TS_24 values ranging from 2.13 to 2.92% for cement-bonded boards produced using *Areca catechu* stem particles. E-25 and EF-25 both boards produced in this study have lower density than the stated study. Almost all of the results found in this study are lower than the results of the stated study.

Soares Del Menezzi *et al.* (2007) produced wood-cement board from oriented strands and silica fume. They reported values of TS_24 as 9 to 10.5%.

4.2 Mechanical properties

The mechanical properties of modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and surface soundness (SS) were studied at 95% significance level. All of the properties are summarized in Table 5.

Table 5. Summary of the mechanical properties of the produced CBPBs

Types of Boards	Types of Properties			
	MOE (MPa)	MOR (MPa)	IB (MPa)	SS (MPa)
Control	5038.35	9.31	1.34	1.05
E-05	3640.64	5.95	0.63	0.75
E-10	2992.66	5.31	0.49	0.61
E-15	2347.01	4.07	0.30	0.51
E-20	2025.66	3.84	0.24	0.38
E-25	1740.89	3.05	0.21	0.26
EF-25	4675.38	6.41	0.67	0.37

4.2.1 Modulus of elasticity (MOE)

Variation of the mean values of MOE is shown in Figure 6. A decreasing pattern was observed with the increasing percentage of EPS aggregates, except board EF-25 (df=6, F=772, P<0.05. This might have occurred due to the very low density and lower mechanical properties of EPS. Moreover bonding property between cement and EPS might have also some effect on the mechanical properties of the produced CBPB. But a very good MOE value was obtained from EF-25 board, which resulted in the second highest MOE value in spite of having the lowest density. This might have occurred because of the added jute fibers. As the tensile strength of bonded cement is very low, it might have contributed in this reduction pattern.

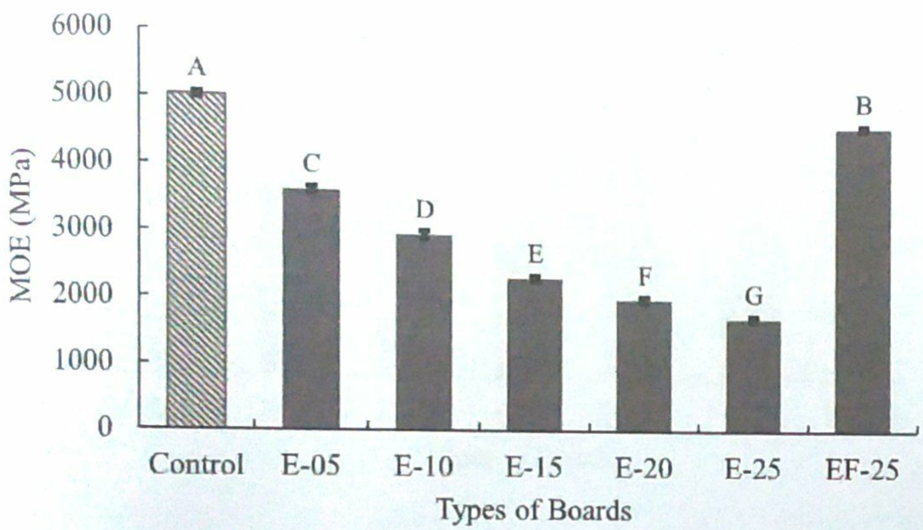

Fig. 6. Average MOE values of different types of boards.

Das *et al.* (2012) produced cement-bonded board from bamboo wastage chips and cement, using different mixing ratio. They found MOE values from 28.81 to 106.11 MPa. All the results found in this study are higher than the results of the stated one.

Ghosh *et al.* (2015) found MOE values of 280 to 320 MPa from cement-bonded boards produced using *Areca catechu* stem particles. All the results found in this study are higher than the results of the stated one.

Nasser *et al.* (2014) got MOE from 3952 to 5678 MPa for cement-bonded board produced from different tree species. Results are similar to this study.

4.2.2 Modulus of rupture (MOR)

Variation of the mean values of MOR is shown in Figure 7. Found similar pattern as the results for MOE values. Higher percentage of EPS gradually reduced the MOR of the produced CBPB (df=6, F=29, P<0.05). Second highest MOR value obtained from EF-25 board in spite of having the lowest density. As discussed in the previous result of MOE jute fiber also helped to improve the MOR of CBPB. Increased MOE and MOR value of EF-25 indicates that jute fibers develop the tensile strength which help to improve the mechanical properties of the CBPB.

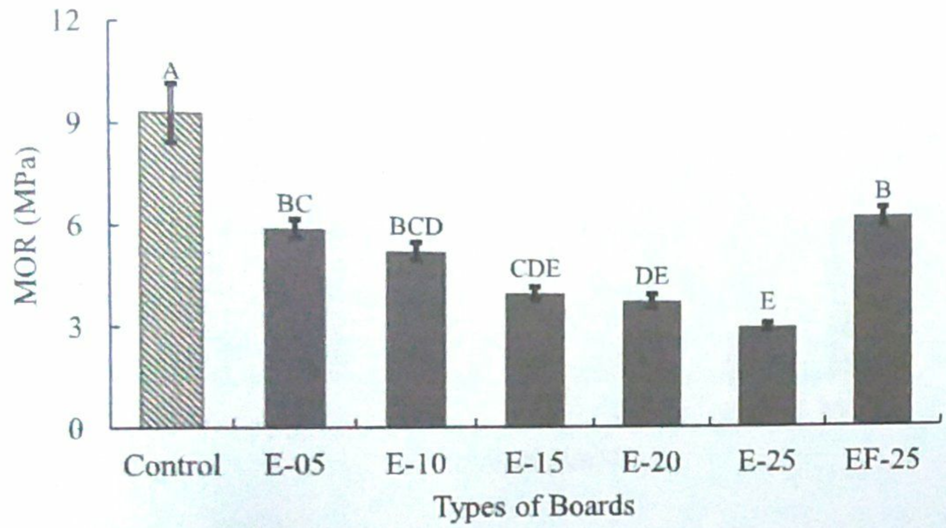

Fig. 7. Average MOR values of different types of boards.

Das *et al.* (2012) produced cement-bonded board from bamboo wastage chips and cement, using different mixing ratio. They found MOR values of 0.98 to 2.46 MPa for boards produced using a cold press for 24 hours. All the results found in this study are higher than the results of the stated study.

Ghosh *et al.* (2015) found MOR values from 3.68 to 4.05 MPa for cement-bonded boards produced from *Areca catechu* stem particles. Almost all of the results found in this study are higher than the results found in the stated study.

Nasser *et al.* (2014) got MOR values from 9.68 to 11.78 MPa for cement-bonded boards having densities around 1.2 g/cc produced from different tree species. Results are higher than this study, might because of wood particles and higher board density.

4.2.3 Internal bond (IB)

Variation of the mean values of IB is shown in Figure 8. Found similar pattern as the results for other mechanical properties. Higher percentage of EPS gradually reduced the IB of the produced CBPB (df=6, F=96.2, P<0.05). Second highest MOR value obtained from EF-25 board in spite of having the lowest density. As the previous properties, jute fiber helped to improve the IB of CBPB. Increased IB value of EF-25 indicates a positive role of jute fibers in IB, which might have contributed to the improvement of other mechanical properties of the CBPB.

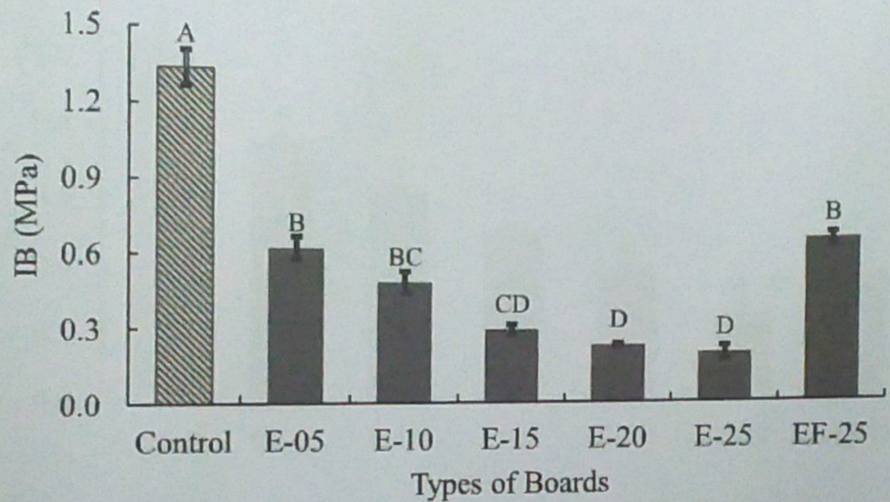

Fig. 8. Average IB values of different types of boards.

Soares Del Menezzi *et al.* (2007) produced wood-cement board from oriented strands and silica fume. They reported values of IB less than .30 MPa all different boards. The obtained values in this study are higher for most of the boards.

Nasser *et al.* (2014) got IB values from 1.49 to 1.73 MPa for cement-bonded boards having densities around 1.2 g/cc produced from different tree species having a wood to cement ratio of 1/3. Results are higher than this study. Higher values might have resulted because of using only wood particles which have higher mechanical properties in comparison with jute sick particles. Higher mixing ratio and higher density of produced board might have also improved the quality.

4.2.4 Surface soundness (SS)

Variation of the mean values of IB is shown in Figure 9. Found similar pattern as the results for other mechanical properties. Higher percentage of EPS gradually reduced the IB of the produced CBPB (df=6, F=144.3, P<0.05). As the previous properties, jute fibers in EF-25 board helped to improve the surface soundness of CBPB than the previous one E-25 having no jute fiber. Thus, from the results it can be concluded that jute fiber can also improve the surface soundness of CBPB produced by integrating EPS.

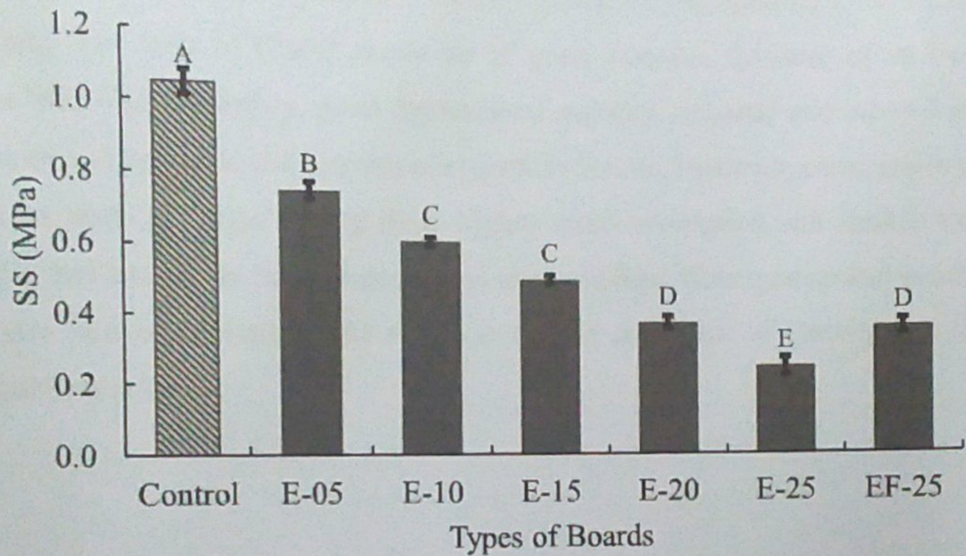

Fig. 9. Average SS values of different types of boards.

Shalbafan *et al.* (2013) found surface soundness values around 1.2 MPa for produced foam core sandwich panels. They got better results and the cause might be the production process. They produced the boards by using EPS layer as the core and fine particles for the surface. Results found in this study might indicate that integration of EPS in mixture reduce the property. Some other surface treatment like lamination might improve the property.

5 Conclusion

CBPB production might be a very good opportunity for the wood based industries in Bangladesh. All the raw materials needed for the production are easily available. As Bangladesh is an agrarian country, lots of raw materials can be collected and utilized which are presently considered as waste. The process of production is also simple. According to the results found in this study, density of CBPB, which is presently one of the major problems can be minimized significantly by using agricultural residues and EPS. The reduced mechanical properties caused by the EPS can be recovered by integrating some natural fibers, such as jute. The uses of CBPB might be of great varieties, because of its exceptional properties like, high durability, good dimensional stability, acoustic and thermal insulation properties etc. compared to the conventional particle boards. However, some major problems still remains such as longer curing time, higher water absorption and further studies are needed. Further studies on particle geometry, compatibility, fiber quality and quantity, EPS particle size and percentage might result in further reduction of density and increased mechanical properties.

References

Amel, B.A. Paridah, M.T. Rahim, S. Osman, Z. Zakiah, A. and Ahmed, S.H. (2014). Effects of kenaf bast fibres on hydration behaviour of cement, *Journal of Tropical Forest Science*, pp. 340–346.

Chang, A.F.-C. (2006). Literature review On Properties and Market Opportunities of Wood-Plastic and Wood-Cement Composites, .

Chen, B. Liu, J. and Chen, L. (2010). Experimental study of lightweight expanded polystyrene aggregate concrete containing silica fume and polypropylene fibers, *Journal of Shanghai Jiaotong University (Science)*, 15(2), pp. 129–137.

Chow, P. (1974). Dry formed composite board from selected agricultural residues, *World Consultation on Wood Based Panels. New Delhi, India: Food and Agriculture Organization of the United Nations*.

Das, A.K. Billha, M. Shams, M.I. and Hannan, M.O. (2012). Physical and mechanical properties of bamboo wastage cement bonded board, *Journal of the Indian Academy of Wood Science*, 9(2), pp. 170–175.

Dissanayake, D. Jayasinghe, C. and Jayasinghe, M.T.R. (2017). A comparative embodied energy analysis of a house with recycled expanded polystyrene (EPS) based foam concrete wall panels, *Energy and Buildings*, 135, pp. 85–94.

Eusebio, D.A. (2003). Cement bonded board: Today's alternative, in *Technical Forum in celebration of the PCIERD 21 st anniversary*.

Evans, D.P. (2000). An Introduction to Wood Cemen-Composite, *Proceeding Wood-Cement Composite in the Asia-Pacific Region*, pp. 7–10.

Fernandez, E.C. and Taja-on, V.P. (2002). The use and processing of rice straw in the manufacture of cement-bonded fibreboard, in *ACIAR PROCEEDINGS*, ACIAR; 1998.

Ferrándiz-Mas, V. Sarabia, L.A. Ortiz, M.C. Cheeseman, C.R. and García-Alcocel, E. (2016). Design of bespoke lightweight cement mortars containing waste expanded polystyrene by experimental statistical methods, *Materials & Design*, 89, pp. 901–912.

Ferreira, S.R. de Andrade Silva, F. Lima, P.R.L. and Toledo Filho, R.D. (2017). Effect of hornification on the structure, tensile behavior and fiber matrix bond of sisal, jute and curauá fiber cement based composite systems, *Construction and Building Materials*, 139, pp. 551–561.

Frybort, S. Mauritz, R. Teischinger, A. and Müller, U. (2008). Cement bonded composites - A mechanical review, *BioResources*, Available at: https://doi.org/10.15376/BIORES.3.2.602-626.

Ghosh, R.K. Rahman, M.M. Das, A.K. Rana, R. and Shams, M.I. (2015). Introducing Areca catechu as a raw material of cement-bonded board through determining the properties of Areca catechu cement-bonded board, *Journal of the Indian Academy of Wood Science*, 12(2), pp. 99–103, Available at: https://doi.org/10.1007/s13196-015-0150-6.

Gray, J.E. (2011). *Polystyrene: Properties, Performance and Applications*, Nova Science Publishers.

IJIRA (2010). *Development of jute-bamboo composites for application in rural areas*, Retrieved from http://www.ijira.org/r-and-d/r&d-projects-in-last-ten-years/html/5.html.

Jorge, F.C. Pereira, C. and Ferreira, J.M.F. (2004). Wood-cement composites: a review, *Holz Als Roh-Und Werkstoff*, 62(5), pp. 370–377.

Kan, A. and Demirboğa, R. (2009). A new technique of processing for waste-expanded polystyrene foams as aggregates, *Journal of Materials Processing Technology*, 209(6), pp. 2994–3000.

Karade, S.R. (2010). Cement-bonded composites from lignocellulosic wastes, *Construction and Building Materials*, Available at: https://doi.org/10.1016/j.conbuildmat.2010.02.003.

Karade, S.R. (2011). Developments in cement-bonded composite material technology, .

Laukaitis, A. Žurauskas, R. and Kerien, J. (2005). The effect of foam polystyrene granules on cement composite properties, *Cement and Concrete Composites*, 27(1), pp. 41–47.

Ma, L.F. Yamauchi, H. Pulido, O.R. Sasaki, H. Kawai, S. and Evans, P.D. (2002). Production and properties of oriented cement-bonded boards from sugi (Cryptomeria japonica D. Don), in *ACIAR PROCEEDINGS*, ACIAR; 1998.

Mindess, S. Young, J.F. and Darwin, D. (2003). *Concrete*, 2nd ed., Prentice Hall.

Morsy, M.I.N. (2011). Properties of rice straw cementitious composite, , Technische Universität.

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

Nagadomi, W. Kuroki, Y. Eusebio, D.A. Ma, L.F. Kawai, S. and Sasaki, H. (1996). Rapid curing of cement-bonded particleboard. 3. Effect of sodium hydrogen carbonate and some cement hardening accelerators, *Mokuzai Gakkaishi*, 42(8), pp. 762–768.

Nasser, R.A. Al-Mefarrej, H.A. Abdel-Aal, M.A. and Alshahrani, T.S. (2014). Effects of tree species and wood particle size on the properties of cement-bonded particleboard manufacturing from tree prunings, *Journal of Environmental Biology*, 35(5), pp. 961.

Onuaguluchi, O. and Banthia, N. (2016). Plant-based natural fibre reinforced cement composites: A review, *Cement and Concrete Composites*, Available at: https://doi.org/10.1016/j.cemconcomp.2016.02.014.

Ross, R.J. (2010). Wood handbook: Wood as an engineering material, .

Salehuddin, A.B.M. (1992). Wood and fibre composite materials, .

Sarkar, M. Asaduzzaman, M. Das, A.K. Hannan, M.O. and Shams, M.I. (2012). Mechanical properties and dimensional stability of cement bonded particleboard from rice husk and sawdust, *Bangladesh Journal of Scientific and Industrial Research*, 47(3), pp. 273–278.

Shalbafan, A. (2013). Investigation of foam materials to be used in lightweight wood based composites, .

Shalbafan, A. Welling, J. and Luedtke, J. (2013). Effect of processing parameters on physical and structural properties of lightweight foam core sandwich panels, *Wood Material Science & Engineering*, 8(1), pp. 1–12.

Sheng, Z.X. Li, L. and Yue, R.Q. (2004). The review of the development of chinese particleboard industry, *China Wood-Based Panels*, 10, pp. 5.

Shrivastava, M. (1997). *Introduction to Forestry*, Vikas Publishing House, New Delhi.

Soares Del Menezzi, C.H. Gomes de Castro, V. and Rabelo de Souza, M. (2007). Production and properties of a medium density wood-cement boards produced with oriented strands and silica fume, *Maderas. Ciencia Y Tecnología*, 9(2), pp. 105–115.

Sotannde, O.A. Oluwadare, A.O. Ogedoh, O. and Adeogun, P.F. (2012). Evaluation of Cement-Bonded Particle Board Produced From Afzelia Africana Wood Residues, *Journal of Engineering Science and Technology*, 7(6), pp. 732–743.

Sukartana, P. Rushelia, R. and Sulastiningsih, I.M. (2002). Resistance of wood-and bamboo-cement boards to subterranean termite Coptotermes gestroi Wasmann (Isoptera: Rhinotermitidae), in *ACIAR PROCEEDINGS*, ACIAR; 1998.

Taylor, H.F.W. (1997). *Cement chemistry*, 2nd ed., Thomas Telford.

Väisänen, T. Haapala, A. Lappalainen, R. and Tomppo, L. (2016). Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review, *Waste Management*, 54, pp. 62–73.

Van Elten, G.J. (1996). Innovation in the Production of Cement Bonded Particle Board and Wool Wool Cement Board, in *at the 5th International Inorganic Bonded Wood and Fiber Composite Materials Conference, IIBCC, Spokane, Washington, USA*.

Wu, Y. Wang, J.-Y. Monteiro, P.J.M. and Zhang, M.-H. (2015). Development of ultra-lightweight cement composites with low thermal conductivity and high specific strength for energy efficient buildings, *Construction and Building Materials*, 87, pp. 100–112.

Zhou, Y.G. and Kamdem, D.P. (2002). Effect of cement/wood ratio on the properties of cement-bonded particleboard using CCA-treated wood removed from service, *Forest Products Journal*, 52(3), pp. 77–81.