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INTRODUCING FASTER SETTING CEMENT-BONDED COMPOSITES FROM AGRICULTURAL WASTAGES

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DEDICATED TO

MY BELOVED PARENTS...

DECLARATION

I am Nafisa Afrin, hereby declare that this thesis paper is the result of my own works and it has not been submitted or accepted for acceptance degree in any other university.

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ABSTRACT

Cement-bonded particleboards possess properties such as high moisture resistance and dimensionally stability when subjected to water soaking and may serve as cheap construction material for walls and roofing of houses, high resistance to white-rot and brown-rot fungi and r high resistance to fire. The increase in cement content of the boards and introduction of chemical additives lowers the water absorption and thickness swelling of the boards. Increase in cement content of the boards, pretreatment of lignocellulosic materials and addition of chemical additives significantly influence the particleboard density, internal bonding strength, modulus of rupture, modulus of elasticity, water absorption capacity and compressive strength of the particleboard. But one of the major problems of CBPB is its higher curing time. Thus, studies are being carried out to solve the problem. This study was designed in such way that chemical additives and Rice husk ash both were used as raw materials for further curing of the CBPB. Moreover, as calcium chloride and magnesium chloride reduce the setting time significantly, jute fibers were integrated to know its effect on density, other physical as well as mechanical properties. The significant result was found for Calcium chloride treated boards and calcium chloride along with rice husk ash contained board types respectively. Jute fiber integration significantly improved the mechanical properties to a satisfactory level. The results thus prove that, Calcium chloride with rice husk ash can be integrated in CBPB to reduce curing time and at the same time our wastage agricultural residues are used.

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1 Introduction

1.1 Background of the Study

Cement-bonded particle board (CBPB) is a composite product that is made with wood particles/fibers and ordinary Portland cement as the binding agent (Olorunnisola, 2007). Particleboard prepared by using mineral cement as the binding agent is gradually gaining importance in many countries of the world. In recent years, some products for structural applications have been developed such as cement-strand slab (Miyatake *et al.*, 2000), cement-bonded composite beams (Bejo *et al.*, 2005) and cement-bonded oriented strand boards (Papadopoulos *et al.*, 2006). Cement-bonded particle board (CBPB) are already used thoroughly in Europe, United States, Russia and S.E. Asia, mainly for roofs, floors and walls (Menezzi *et al.*, 2008).

Cement bonded composites have some advantages in comparison with resin-bonded composites: high durability, good dimensional stability and low production cost (Eusebio 2003, Falk 1994, Moslemi 1988). Besides, mineral composites generally use solid wood waste or other lignocellulosic material, including agricultural wastes like rice husk and straw, wheat straw, bagasse, jute sticks and saw dust (Kasai *et al.*, 1998). 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 residue as in the production of CBPB would reduce the pressure on wood and at the same time might increase the economic value of jute. For this reason, these panels occupy a special place in the new eco-friendly economy as they provide for energy saving, conservation of natural resources and reduction in environmental pollution (Sudin and Swamy, 2006).

Although the properties of the cement-boned composites are also influenced by various parameters like press time and temperature, accelerators and water: cement ratio, the hydration rate of wood-cement composite is of prime importance (Sellers *et al.*, 1993; Kojita *et al.*, 1998; Cheng, 2000; Ohnishi *et al.*, 2000; Okuma and Laemsak, 2000). These compounds are well known as cement set retarders (Sarkar *et al.*, 2012). Cement bonded boards (CBB) are manufactured by using lignocellulosic materials as raw materials and to reduce the density, curing time and water absorption, these are treated with different low-density materials, chemical additives, water repellents etc. (Okino *et al.*, 2005; Islam *et al.*, 2013; Brasileiro *et al.*, 2013).

Till now setting time of cement creates problem for manufacturing cement-bonded particleboard but the addition of chemical additives helps to set the board quickly (Jorge *et al.*, 2004). Extraordinarily long pressing and clamping times represent a huge problem in manufacturing CBCs due to cost-intensiveness, as pressing should continue until the maximum hydration temperature is reached (Badejo *et al.*, 2011). Different methods are applied to reduce the setting time in the production, either by the addition of assorted admixtures, an increase in temperature during pressing or clamping, or by the use of CO_2 during pressing and/or clamping (Young *et al.*, 1974; Simatupang *et al.*, 1991; Geimer *et al.*, 1993; Simatupang and Habighorst 1993a,b,c; Simatupang and Neubauer 1993; Wagh *et al.*, 1994; Geimer *et al.*, 1994; Simatupang *et al.*, 1995; Wagh *et al.*, 1997;Simatupang and Bröker 1998; Hermawan *et al.*, 2000; Hermawan *et al.*, 2002b; Soroushian *et al.*, 2003; Soroushian *et al.*, 2004;Qi *et al.*, 2006;Qi and Cooper 2007;). Several accelerators, including NaOH, $CaCl_2$, Na_2CO_3, and NH_4Cl were tested concerning their potency to shorten the setting and curing time as well as improving the specific properties of CBCs (Moslemi *et al.*, 1983; Hofstrand *et al.*, 1984; Kavvouras 1987; Badejo 1988; Hermawan *et al.*, 2002b; Hermawan *et al.*, 2002b; Bejó *et al.*, 2005; Papadopoulos *et al.*, 2006). The use of CO_2 is a promising method to accelerate the hydration process (Geimer *et al.*, 1992; Simatupang and Habighorst,1992; Hermawan *et al.*, 2002a). Under the influence of pressurized CO_2, the hydration of cement is enhanced so that demolding can be accomplished after three minutes (Simatupang and Habighorst, 1992).

Chemical additives ($CaCl_2$, $MgCl_2$) are normally used as accelerators, which often accelerate cement hydration and reduce set time by as much as two thirds. Even incorporation of chemical additives improves the bonding of particles to cement (Simatupang *et al.*, 1991). Several chemicals are used as accelerators to increase in the rate of setting in such composites. However, calcium ($CaCl_2$) is most widely used due to its predictable performance characteristics and successful application in concrete works over several decades. Addition of $CaCl_2$ improves cement curing by reducing moisture loss through evaporation during early hydration period by releasing the normal heat of hydration earlier and by accelerating the hydrating action. The amount of calcium chloride used should not exceed 2% and for $MgCl_2$ it should not exceed 1.5% of solution (Wolfe and Gjinolli, 1996).

In some cases, the addition of small amounts of cement setting accelerators, such as $CaCl_2$ or $MgCl_2$, can even eliminate the need to pre-soak the wood particles (Semple and Evans, 2004). The coating of the wooden particles prior to mixing with cement is a possibility to improve compatibility. On this issue, Okino *et al.*, (2005) describe the use of $CaCl_2$ as an aqueous solution. Another promising method, which additionally accelerates setting as well as curing time and improves mechanical properties, is the use of gaseous or supercritical CO_2 (Hermawan *et al.*, 2002a, b; Hermawan *et al.*, 2001a; Hermawan *et al.*, 2000; Geimer *et al.*, 1994; Geimer *et al.*, 1993; Simatupang and Habighorst 1992; Simatupang *et al.*, 1991). The high production levels of calcium silicate hydrate and calcium carbonate during the hydration of cement, and the interaction between those hydration products with wood surfaces are considered to be the main reasons for the superior strength properties obtained in CO_2-cured boards (Hermawan *et al.*, 2001a). Another approach is the replacement of parts of cement by fumed silica (SiO_2) in combination with superplasticizers. This combination should increase the cohesiveness of the fresh composite and reduce the water content (Okino *et al.*, 2005). Also, Meneéis *et al.*, (2007) observed an improvement of mechanical properties as well as mitigation of thickness swelling when fumed silica (10%) was added. However, Moslemi *et al.*, (1994) could not confirm the positive effects of fumed silica. On the contrary, the addition of laboratory-grade fumed silica resulted in the reduction of most board strength properties. Fast setting cement mixtures are also promising as the binder set much faster and give no time to wash out extractives into the cement slurry (Bietz and Uschmann, 1984; Simatupang *et al.*, 1991).

Thus, this study was carried out to reduce the setting time of CBPB by using $CaCl_2$ and $MgCl_2$ as chemical additives along with agricultural residues (jute sticks and rice husk). If become successful, this study might make a new innovation in the field of composite product.

1.2 Objectives of the Study

Accelerated curing is any method by which high early age strength is achieved in concrete. These techniques are especially useful in the prefabrication industry, where in high early age strength enables the removal of the formwork within 24 hours, thereby reducing the cycle time, resulting in cost-saving benefits (Paya *et al.*, 1995) At heightened temperatures, the hydration process moves more rapidly and the formation of the Calcium Silicate Hydrate crystals is more rapid. The formation of the gel and colloid is more rapid and the rate of diffusion of the gel is also higher. However, the reaction being more rapid leaves lesser time for the hydration products to arrange suitably, hence the later age strength or the final compressive strength attained is lower in comparison to normally cured concrete. Pozzolana increases the later age strength of concrete as it reacts with calcium hydroxide and turns it into calcium-silicate-hydrates (C-S-H). However, Portland pozzolanas cements have higher activation energy and therefore, their rate of hydration is lower as compared to ordinary Portland cement (OPC). This results in lower early age strength as compared to OPC. Accelerated curing techniques radically help to increase the rate of strength gain. Halit *et al.*, (2005) showed that steam curing improved the 1-day compressive strength values of high volume fly ash concrete mixtures (40%, 50% and 60% fly ash by replacement) from 10MPa to about 20MPa which is sufficient to enable the removal of formwork and greatly aids the precast concrete industry. This study addressed faster setting CBPB for industrial use in Bangladesh and reduce time. This research was conducted with the following specific objectives:

- To produce faster setting cement-bonded particle board (CBPB)using OPC, jute sticks, rice husk ash (RHA) and, additives ($CaCl_2$, $MgCl_2$).
- To assess the physical and mechanical properties of the produced CBPB.

2 Literature Review

2.1 General information about particleboard

Particleboard is defined as a panel product manufactured from lignocellulosic materials, primarily in the form of discrete particles, combined with a synthetic resin or other suitable binder and bonded together under heat and pressure (Nemli and Aydin, 2007). The major types of particles used to manufacture particleboard include wood shavings, flakes, wafers, chips, sawdust, strands, slivers, and wood wool. Particle board is cheaper, denser and more uniform than conventional wood and plywood and is substituted for them when cost is more important than strength and appearance. However, particleboard can be made more attractive by painting or the use of wood veneers onto surfaces that will be visible. Though it is denser than conventional wood, it is the lightest and weakest type of fiberboard, except for insulation board (Wang *et al.*, 2008).

2.1.1 History and development of particleboard

Particleboard originated in Germany. It was first produced in 1887, when Hubbard made so-called "artificial wood" from wood flour and an adhesive based on albumin, which was consolidated under high temperature and pressure (Rowell *et al.*, 2013). Although the use of two or three layers of wood veneer is ancient, modern sheets of plywood with 5-11 core layers of veneer were invented in the early 20th century and began to become common by the Second World War. During the war, phenolic resin was more readily accessible than top grade wood veneer in Germany, and Luftwaffe pilot and inventor Max Himmel Heber played a role in making the first sheets of particleboard, which were little more than pouring of floor sweepings, wood chips, and ground up off-cuts and glue. The first commercial piece was produced during World War II at a factory in Bremen, Germany (Moslemi, 1985). For its production, waste material was used - such as planer shavings, offcuts or sawdust - hammer-milled into chips and bound together with a phenolic resin. It was found that better strength, appearance and resin economy could be achieved by using more uniform, manufactured chips. Producers began processing solid birch, beech, alder, pine and spruce into consistent chips and flakes; these finer layers were then placed on the outside of the board, with its core composed of coarser, cheaper chips. This type of board is known as three-layer particleboard. More recently, graded-density particleboard has also evolved. It contains particles that gradually become smaller as they get closer to the surface (Çolak *et al.*, 2007).

2.2 General information about cement-bonded composite

Over the last years promising cement bonded wood composites for structural purposes have evolved. Durability, toughness, high dimensional stability, resistance against environmental influences such as biodegradation or weathering but also availability of the raw material as well as economic factors are features which can make cement-bonded composites superior to conventionally bonded composites. In the beginning cement bonded composites (CBCs), particularly low-density boards, were mainly used for insulating purposes. In 1973, a Swiss company called Durisol was among the first manufacturers that produced a building panel consisting of small wood particles bonded in a cement matrix (Wolfe and Gjinolli, 1996b). Many composites have evolved in the last decades, e.g. cement-bonded wood wool boards (CBWW), cement-bonded particleboards (CBPB), and fiber-reinforced cement boards. These CBCs are used for thermal as well as acoustic insulation purposes and consist of particles of different sizes (strands, flakes, chips, fibers). In recent years some products for structural use have been developed, e.g. cement bonded Oriented Strand Board (OSB) (Ntalos and Papadopoulos 2006; Papadopoulos *et al.*, 2006), cement strand slab (Miyatake *et al.*, 2000), or cement bonded composite beams (Bejó *et al.*, 2005; Datye and Gore, 1998). In comparison to wood and conventional wood products the CBCs are highly fire-, termite- and water-resistant. On the other hand, for some applications CBCs are competitive with reinforced concrete because of their relatively low density (Bejó *et al.*, 2005).

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).

Wood Wool Cement Board is a versatile, ecologically pure and safe construction material, meeting all criteria of comfortable and safe housing. WWCB is made of wood wool and Portland cement with addition of natural mineralizing agent. High content of wood in WWCB makes them similar by ecological properties to wood mass, at the same time; the cement provides WWCB with durability and long service life, allows using them as a perfect construction material. Wood wool is a band-like fibers 0,2 - 0,5mm thick, 3 - 5 mm wide and up to 25 mm long, cut on the special equipment. It has a function of filler in content of fiberboard. Due to this feature, wood wool slabs have valuable properties of timber, as a natural, ecologically pure material, its strength and perfect thermal insulation. Portland cement is water resistant and frost proof. The content of cement provides ready slabs with durability and long-term service life. Wood strands are first impregnated, and then by pressing they are bonded with cement in the continuous technological process. In this process wood strands become resistant to expanding, insects, rotting, water absorption, and fire resistance is also significantly improved. Testing has proved that the properties of WWCB improve over the years (Evans, 2000).

Cement bonded particle boards have treated wood flakes as reinforcement, whereas in cement fiber boards have cellulose fiber, which is a plant extract as reinforcement. Cement acts as binder in both the cases. The fire resistance properties of cement bonded blue particle boards and cement fiber boards are the same. In terms of load-bearing capacity, cement-bonded particle boards have higher capacity than cement fiber boards. Cement particle boards can be manufactured from 6 mm to 40 mm thickness making it ideally suitable for high load bearing applications (Zhou *et al.*, 2002). These boards are made of a homogeneous mixture and hence are formed as single layer for any thickness. Cement fiber boards are more used in decorative applications and can be manufactured from 3 mm to 20 mm thickness. Fiber boards are made in very thin layers, making it extremely difficult to manufacture high thickness boards. Many manufacturers use additives like mica, aluminium stearate and cenospheres in order to achieve certain board qualities. Typical cement fiber board is made of approximately 40-60% of cement, 20-30% of fillers, 8-10% of cellulose, 10-15% of mica. Other additives like above mentioned aluminium stearate and PVA are normally used in quantities less than 1% (Wolfe and Gjinolli, 1996). Cenospheres are used only in low density boards with quantities between 10-15%. The actual recipe depends on available raw materials and other local factors.

Interest in wood fiber-reinforced cement was sparked by the post-World War II shortage of asbestos fibers, which caused some private companies to consider cellulose fiber as a substitute for asbestos in fiber-reinforced cement. This interest faded as asbestos supplies recovered in the 1950s, but it regained strength by the mid- 1970s with growing concern over the health risks linked to asbestos. Today, cellulose fiber is used in a wide variety of fiber-reinforced cement product, originally developed using asbestos fiber. he primary function of fibers in these cement composites is to increase the energy of fracture (Evans, 2000).

2.3 Detailed information about CBPB

2.3.1 Brief history and development of CBPB

Before particle board, 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. But before that scarcity in raw materials of plywood, first efforts were made in the early 1920s for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. The new technologies introduced in the 1930s in resin applications with the growing demand paved the way for the industrial production of particleboard in the early 1940s. The first commercial piece was produced during World War II at a factory in Bremen, Germany. It was used waste material such as planer shavings, off-cuts or sawdust, hammer-milled into chips, and bound together with aphenolic resin. In the early 1960s, a high-density cement bonded structural flake board was developed leading to expand applications (Deppe, 1974). Today, wood cement panels have found acceptance in a number of countries as a result of certain desirable characteristics.

In Indonesia, the first mineral bonded board made of saw dust was established in Palembang. This board used saw dust and shavings as raw materials. In 1970's there were six mineral bonded board mills in Indonesia and four of them used excelsior or wood wool and rest used wood flakes in the mix. CBP established itself in Switzerland and central Europe in the mid 1970's and has been imported in UK since the late 1970's. The number of plants worldwide is over 40, with one in the UK. There were over 38 plants in operation throughout the word (Moslemi, 1989). Currently, there are so many plants, production of cement bonded boards throughout the world. An extensive development of CBP industry has taken place throughout the world during 1980-90 (Desch, 1996). This rapid spread was partly caused by the market looking at that time for replacement sheet materials for asbestos boards. However, CBPB has not exactly the same characteristics as asbestos sheets and therefore the manufacturers had to find also other markets. Some companies in Western Europe, the USA, Mexico and Russia, which did not find other markets in time, had to sell or close down their plants.

But presently, after having found and developed such markets and also due to the improved economy several of the remaining factories can hardly meet the high demand. Most of the European CBPB producers, and some in Russia, now run three or four shifts per day and some also during the weekends, but the European producers still cannot produce enough to maintain also their export to the USA. Therefore, some do have to import a considerable amount of boards from Russia, which in turn causes a greater shortage of boards in that country (Van Elten,1996).

2.3.2 Properties of CBPB

Wood particle sizes, geometry, and varieties will affect properties of WPC (Stark and Rowlands,2003; Takatani *et al.*, 2000; Stark, 1997). The affected properties can include moisture absorption (Wang and Morrell, 2004) and decay resistance (Verhey and Laks, 2002). In general, the hardwoods WPC exhibited slightly better tensile and flexural properties and heat deflection temperatures compared to the softwoods WPC (Stark, 1997). The formulation, including the contents of wood, plastic and additives, can significantly affect the properties of wood-plastic composites (Wolcott 2003; Stark and Rowlands, 2003; Lu *et al.*, 2000; Caulfield *et al.*, 1998; Hwang 1997; Stark, 1997). WPC typically containing approximate 50% wood flour, although some composites contain very little wood or as much as 70% wood (Clemons, 2002). The higher filler content, the better stiffness properties; however, the MOR and maximum deflection decrease with increasing wood content and decreasing resin content of particles (Hwang, 1997). With increasing wood flour content, flexural and tensile modulus, density, heat deflection temperature, and notched impact energy increased, while flexural and tensile strength, tensile elongation, mold shrinkage, melt flow index, and unnoticed impact energy decreased (Stark, 1997). Finally increasing plastics content will increase the heat release rate of wood-plastic composites (Stark *et al.*, 1997).

Cement bonded board has been found to be a good substitute for concrete hollow blocks, plywood, particle board and other resin bonded boards. It is 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 (Anon, 2001). The properties of cement bonded boards are highly dependent on-board type, thickness and density. Cement bonded boards that not suitable for load bearing elements are often used with farming materials like wood and steel section (Eusebio, 2003). Cement bonded boards properties offer a variety of advantages. One of these includes excellent machinability enabling the manufacture or the user to incorporate intricate cuts or joints. This has facilitated the development of a process by which V shaped groves can be cut into flat panel surfaces. The use of special adhesives enables the manufacture to produce panels with flanges. Such components can be used in the construction of building without the use of studs. The boards can be used in its natural gray color or can be finished with a variety of finishes. Cement bonded particle board offer properties that, in some respects, are unique to this kind of material. These boards generally have a lower modulus of rupture than resin bonded particle-board but are superior in modulus of elasticity (Stillingger and Wentworth, 1977).

2.3.3 Manufacturing process of CBPB

Cement-bonded particleboards were developed in the 1960s and the technology used to produce them shows many similarities to that used to manufacture resin-bonded particleboard (Moslemi and Hamel, 1989). There are differences, however, notably in the storage of wood before manufacture and in the forming and pressing of boards. Debarked logs, usually coniferous species, are stored for at least 2–3 months prior to processing to reduce their moisture and sugar content. Wood particles are then prepared in the same manner as for conventional particleboard. Logs are processed to produce chips approximately 10–30 mm in length and 0.2–0.3 mm in thickness, which are then further reduced in size using knife ring flakers or hammer mills (cooper *et al.*, 2006). The resulting flakes are screened into three classes; fines, 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 the following ratio by weight; wood 20%: cement 60%: water 20%. The moisture content of the flakes is monitored continuously and the volume of water added to the mix is adjusted accordingly. Calcium chloride (2–3% w/w) may be added to the mix to accelerate the setting of the cement After the mixing, cement-coated wood flakes are fed to a forming station where a continuous mat of uniform thickness is deposited on an endless series of caul plates running on a conveyor. The mat is cut into lengths corresponding to the size of the caul plate and a stack of mats is compressed to about a third of its original height over a period of 2–3 min at a pressure of approximately 2.4 N mm-2 (Nagadomi, *et al.*, 1996). While the stack of calls is still in the press, clamping arms are attached to it so that, on release from the press, the batch of mats is still held in a compressed state. These are transferred to a heated chamber at 70–80°C for 6–8 h to facilitate cement hardening. At the end of this period the clamps are released, the calls are removed and the boards are air-dried, trimmed and then stacked for 12–18 days to allow the cement to cure. The boards are further dried and conditioned prior to shipment and can be sanded on one or both sides. Common board thicknesses are 12 and 18 mm, but boards as thin as 8 mm and as thick as 40 mm can be produced (Evans, 2002; Saunders and Davidson, 2014).

2.4 Raw materials used in CBPB

For Cement Bonded Board production different types of raw materials are used such as Cement, Water, Reinforcement materials, and other Chemicals. Every raw material has different types based on final products.

2 .4.1 Ordinary Portland cement (OPC)

When ordinary Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to set. These chemical reactions all involve the addition of water to the basic chemical compounds. This chemical reaction with water is called "hydration". Each one of these reactions occurs at a different time and with different rates. Addition of all these reactions gives the knowledge about how Ordinary Portland cement hardens and gains strength. Those compounds and their role in hardening of cement are as under:

1. **Tricalcium silicate (C_3S):** Hydrates and hardens rapidly and is largely responsible for initial set and early strength. Ordinary Portland cements with higher percentages of C_3S will exhibit higher early strength.
2. **Dicalcium silicate (C_2S):** Hydrates and hardens slowly and is largely responsible for strength increases beyond one week.
3. **Tricalcium aluminate (C_3A):** Hydrates and hardens the quickest. It liberates a large amount of heat almost immediately and contributes somewhat to early strength. Gypsum is added to Ordinary Portland cement to retard C_3A hydration. Without gypsum, C_3A hydration would cause ordinary Portland cement to set almost immediately after adding water.
4. **Tetra calcium aluminoferrite (C_4AF):** Hydrates rapidly but contributes very little to strength. Most ordinary Portland cement color effects are due to C_4AF.

There are two ways in which compounds of the type present in cement can react with water:

In the first, a direct addition of some molecules of water takes place, this being a true reaction of hydration. The second type of reaction with water is hydrolysis, in which its nature can be illustrated using the C_3S hydration equation:

$3CaO.SiO_2+H_2O \rightarrow Ca(OH)_2+ xCaO.ySiO_2.aq.$ (calcium silicate hydrate).

The reaction of C_3S with water continue even when the solution is Saturated with lime and the resulted amounts of lime precipitate in crystals form $Ca(OH)_2$.

Calcium silicate hydrate

→remains stable when it is in contact with the solution saturated with lime.

Calcium silicate hydrate

→hydrolyzed when being in water

-some of lime form, and the process continues until the water saturate with lime.

If the calcium silicate hydrate remains in contact with water it will leave the hardened compound only as hydrated silica due to the hydrolysis of all of the lime.

The rates of the chemical reactions of the main compounds are different:

Aluminates

- React with the water in the beginning
- Affect the route of the chemical reactions at early periods of hydration.

Silicates

-Affect the later stage reactions.

The main hydrates of the hydration process are:

-Calcium silicates hydrate, including hydrated products of C_3S, and C_2S.

$2\ C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$

$2\ C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$

Tricalcium aluminate hydrate.

$C_3A+6H \rightarrow C_3AH_6$- C_4AF hydrates to tricalcium aluminate hydrate and calcium ferrite $CaO.\ Fe_2O_3$ in amorphous form.

Since calcium silicates (C_3S and C_2S)

-are the main cement compounds (occupies about 75% of cement weight)

-they are responsible for the final strength of the hardened cement paste.

Hydration of C_3S - take about one year or more.

This Initial gel form an external layer over C_3S causing the delay of the reaction.

After few hours, this initial C-S-H undergo hydrolysis to form the second product of the gel CSH. The full hydration of C_3S can be expressed Approximately following equation:

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

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 (Salahuddin, 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 (Young Quist, 1999).

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 (Acda, 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 (Al-Tulaian *et al.*, 2016).

2.5 Strategies for CBPB curing time reduction

Extraordinarily long pressing and clamping times represent a huge problem in manufacturing CBCs due to cost-intensiveness, as pressing should continue until the maximum hydration temperature is reached. There are four distinct periods in the hardening or hydration process. The first period occurs when cement and water are brought into contact. It is a period of rapid dissolution and exothermic chemical reactions lasting about 5 min. The rate of reactions then subsides to a low level, and the second period, one of dormancy or plasticity, lasts 40 to 120 min (depending on the cement characteristics). The Third period, one of rapid chemical reactions, then begins, usually lasting 3 to 6 hours, during which the concrete loses its plasticity and sets. Final set commonly occurs by the sixth hour after the cement first comes in contact with water. At that time approximately, 85 percent of the hydration process is still remaining. After final set, the fourth period begins, one in which the chemical reactions continue at a diminishing rate until the conditions necessary for the reactions to continue are no longer present (Pavithra, 2014). When hydration occurs at a rapid pace, there is rapid hardening and rapid gain of strength. Hydration, being an exothermal chemical reaction, gives off heat, and, if heat is applied externally, hydration will accelerate. When the rate of heat evolution is measured at normal temperature and at an elevated temperature (applying heat), it can be seen that the heat evolution at elevated temperatures is greater than at normal temperatures (Rao1 and Kumar, 2010). This implies that the hydration process is accelerated and that the strength gain due to elevated temperatures is also accelerated. Different methods are applied to reduce the setting time in the production, either by the addition of assorted admixtures, an increase in temperature during pressing or clamping, or by the use of CO_2 during pressing and/or clamping (Young *et al.*, 1974; Simatupang *et al.*, 1991; Simatupang and Neubauer, 1993; Geimer *et al.*, 1993; Simatupang and Habighorst, 1993a, b, c; Geimer *et al.*, 1994; Wagh *et al.*, 1994; Simatupang *et al.*, 1995; Wagh *et al.*, 1997; Simatupang and Bröker 1998; Hermawan *et al.*, 2000; Hermawan *et al.*, 2002b; Soroushian *et al.*, 2003; Soroushian *et al.*, 2004; Qi *et al.*, 2006; Qi and Cooper 2007;). Several accelerators, including NaOH, $CaCl_2$, Na_2CO_3, and NH_4Cl, were tested concerning their potency to shorten the setting and curing time as well as improving the specific properties of CBCs (Moslemi *et al.*, 1983; Hofstrand *et al.*, 1984; Kavvouras 1987; Badejo 1988; Hermawan *et al.*, 2002b; Bejó *et al.*, 2005; Papadopoulos *et al.*, 2006). The use of CO_2 is a promising method to accelerate the hydration process (Geimer *et al.*, 1992; Simatupang and Habighorst, 1992; Hermawan *et al.*, 2002a). Under the influence of pressurized CO_2, the hydration of cement is enhanced so that demolding can be accomplished after three minutes (Simatupang and Habighorst, 1992). For the sake of completeness, also fast setting cement mixtures, as described by Simatupang *et al.*, (1991). The addition of CO_2 during pressing reduces the setting time of CBP to a few minutes. Geimer *et al.*, and Simatupang and Habighorst used CO_2 injection to determine its effect on fabrication, pressing variables, and the optimal condition for carbonation. CO_2 injection provides a method for reducing the pressing time of cement-bonded wood composite boards and decreasing wood–cement incompatibility. Qi et *al.*, showed that CO_2 injection in wood–cement composites containing 14% or 20% recycled waste medium density (MDF) fiber resulted in much higher strength and toughness, with lower water absorption properties. Hermawan *et al.*,6 demonstrated the rapid curing process of high-strength CBP using gaseous or supercritical CO_2. This research showed that supercritical CO_2-cured board can be two to three times stronger than untreated board. The addition of CO_2 accompanied by a supercritical fluid might enhance the hydration process of cement and the strength properties of the board (Hermawan *et al.*, 2001).

On the other hand, it has often been reported that CO_2 degrades cement or concrete because of carbonation. Houst reported that the most negative effects of carbonation of cement are lowering of pore solution pH and loss of protection against corrosion of the steel in reinforced concrete. Carbonation also causes a marked increase in porosity and reduction in strength of super-sulfated cement, probably as a result of carbonation of the ettringite. It has not yet been revealed whether the supercritical CO_2 treatment has a positive or negative effect on the performance of CBP over a longer time span. This research aims to clarify the curing and degradation processes of CBP under supercritical CO_2 treatment (Park DC, 2008).

2.5.1 Chemical additives for CBPB

One of the reasons for incorporating chemical additives into cement-bonded boards (CBBs) during production is to improve the bonding of wood particles to cement. Improve bonding between wood particles and cement will definitely result in improvement of the ultimate strength of CBBs. The most common accelerator is calcium chloride ($CaCl_2$). why it accelerates hydration is not completely understood. Evidence suggests $CaCl_2$ may increase the permeability of the C-S-H gel building around each silicate grain and therefore give water ready access to the grain's anhydrous surface. This would shorten the induction period. $CaCl_2$ is normally added to concentrations of 2-4% by weight of cement. Higher concentrations decrease thickening time-equivalent to the length of time the slurry is pumpable (Bakharev, 2005(8b)).

Magnesium chloride ($MgCl_2$) also an effective chemical additive is used in dosages of up to 2% of the weight of cement, following recommendation by the Builder's Guide to accelerate the setting of the wood cement mixture and to increase the early stage strength of the boards.

RHA is a good super-pozzolan. This super-pozzolan can be used in a big way to make special concrete mixes. There is a growing demand for fine amorphous silica in the production of special cement and concrete mixes, high performance concrete, high strength, low permeability concrete. The effect of RHA average particle size and percentage on concrete workability, fresh density, superplasticizer (SP) content and the compressive strength are also investigated. Although grinding RHA would reduce its average particle size (APS), it was not the main factor controlling the surface area and it is thus resulted from RHA's multilayered, angular and microporous surface. Incorporation of RHA in concrete increased water demand. RHA concrete gave excellent improvement in strength for 10% replacement (30.8% increment compared to the control mix), and up to 20% of cement could be valuably replaced with RHA without adversely affecting the strength. Increasing RHA fineness enhanced the strength of blended concrete compared to coarser RHA and control OPC mixtures.

2.6 Applications of CBPB

Successful new applications in Western Europe, different from that of asbestos boards, are amongst others: -Flooring with tongue and grooved boards; -Large size prefabricated elements for permanent shuttering of concrete walls and floors -The production of complete prefabricated houses. Depending on cultures and building codes, the developments in the market since 1970 for CBPB are very different in various countries, which is also depending on price and quality of the boards. Amroc in Magdeburg, Germany, which company has Eltomation mixing, dosing and distributing equipment for narrow thickness tolerances, recently reported the distribution of their high standard CBPB Class B1 and high fire-resistant boards Class A2 in Western Europe as follows:

Table: 1 Approximate distribution for the CBPB applications

Percentage (%)	Application of CBPB
15%	Floors
20%	Office containers, influenced by new governmental fire and moisture regulations
15%	Supply to prefabricated house manufacturers
25%	Various supplies to the industry, amongst others for kitchens, bathrooms and furniture.
5%	Facades
20%	Various, including high fire-resistant Class A_2 boards.

A fast expanding application in Western Europe and Russia is for prefabrication of large elements for permanent shuttering of concrete walls as licensed by the company VST GROUP in Vienna, Austria. For the assembly of the elements VST uses spacers of steel, and for a similar system, the DUO-MASSIV system, spacers of strong plastic are used. In the factory the elements are already provided with all openings, reinforcing, tubing and piping. At the building site the wall and floor elements are filled with concrete of local ready-mix suppliers. For the assembly of DUO -MASSIVE elements, Eltomation supplies automatic equipment (Van elten, 2000).

Although the first CBPB products and the production plants have been developed in Western Europe, we must admit that with further developments and perfections of the boards, the Japanese producers are ahead with certain special products and applications. Especially in view of perfections of sophisticated embossed and painted CBPB for exterior cladding of homes and other buildings. These Figures show.

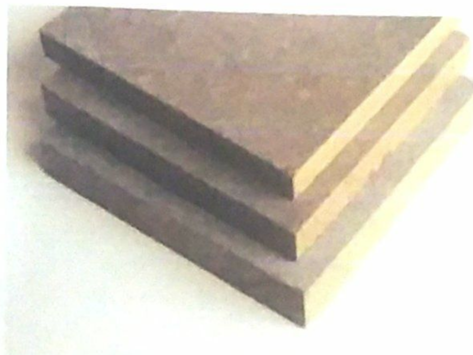

Fig.1. Cross-cut of 40 mm CBPB panel (Van elten, 2000).

Waste Management

To reduce the amount of wasted material several steps are taken to prevent and re-use waste materials. Fresh material from the ends of the cauls at the caul accelerating station, from the fresh board weight checking station and from the board lengthening machine is fed back to the mixing area and re-used. Pretrimmed material from 8 hours cured board is also re-used after refining, storing and dosing. Up to 5% of this relatively fresh material may be added to the fresh mixture in the mixer without harm to the quality of the boards. Only a little amount of final trimmed-off material after drying has to be dumped (Van elten, 2006).

Embossed surfaces

Not new, but still not widely known are CBPB boards with embossed and coated surfaces in various configurations like brickwork, wood grain or natural stone. Especially in Japan these boards are very successful. More than 90% of the Japanese CBPB boards have an embossed and coated surface and are used for exterior wall claddings (Figure 2). Based upon the success in Japan, several companies in various other countries are now testing the market for these boards. The surfaces are usually rolled or spray painted in the desired colors for which nowadays various suitable paints and coatings are available. The profiled moulds (cauls) of fiber reinforced hard plastics with embossed surfaces are so stiff and strong that they can replace the normal steel caul, however once in every 5 to 10 boards an extra steel caul may be added for extra stiffness.

Fig.2. Embossed and painted CBPB for wall claddings (Van elten, 2004).

Shingles

Also, not new but very interesting is the development of CBPB shingles. In Hungary applications of painted and unpainted shingles on walls and roofs are common, but of special interest are the roof and wall shingles developed in some states in western USA. No doubt the notorious bush fires in California and Sidney, Australia and the influence of insurance companies help to promote these nice looking and inflammable shingles in the market (Van elten, 2006). In Figure 4 wood grain structured CBPB shingles are stapled to a roof construction in California.

Fig.3. Imitation Roofing Shakes of embossed and painted CBPB (Van elten, 2006).

Prefabricated wall and floor panels

Eltomation is involved in the development of a plant for the production of large hollow CBPB wall and floor panels with an overall thickness of 15 to 30 cm, a wall height up to 280 cm and a length up to 600 cm. Figure 4 shows part of such a panel. Given the complicated moulds with expandable hydraulic retractable bodies and the very special press a CO_2 hardening process is applied. With this process only a few moulds are required. About every ten minutes one large panel can be produced. The system will be developed in such a way that also large size sheet panels e.g. for shuttering of monolithic concrete can be produced. A pilot plant for the production of 120 x 300 cm panels is currently being installed at the Amroc/Zehoma CBPB plant in Magdeburg, Germany.

Fig.5.CBPB hollow wall panel (Website of Eltomation BV)

Permanent shuttering of concrete

Very interesting is the successful application of large size prefabricated wall and floor elements assembled of CBPB panels on the computer operated DUO-TEC assembly line. The computer program is simultaneously created by the architect while designing the building. At the same time all calculation work is done by computer. The elements consist of CBPB panels, spaced with metal or high tensile plastic spacers and have the required internal reinforcements installed. Each element is precisely cut to the exact dimensions at the factory, including openings for cables, pipes, ducts, doors and windows. On site the prefab elements only have to be installed and filled with concrete, creating a monolithic construction. Before the concrete is poured, piping for water, gas and electricity can easily be installed in the hollow walls. After the construction of the building the outer walls are insulated with 7 cm thick sheets of Styrofoam which are finished with a thin layer of elastic stucco or finish. Figure 7 shows the front of such an apartment building under construction in Vienna, Austria (Van elten, 2004). Three laborers only were needed to install all walls and floors for one storey each week. Due to the prefab system, this fast and highly efficient building method causes no dust, waste or the usual noise on the building site and provides for a quick return on investment. Figure 6 shows the preparation at the CBPB floor units before being filled with concrete.

Fig.6. Installation the CBPB prefab floor units (Van elten, 2004).

Fig.7. Permanent shuttering with CBPB prefab elements (Van elten, 2006).

Fig.8. Complex of apartments in Osterweddingen under construction and Fig.9. Complex of apartments in Osterweddigen build with the DUO-MASSIV system (Van elten, 2006).

Figure 9 shows a picture of a complex of apartments built with the DUO-MASSIV permanent shuttering system in Osterweddingen near Magdeburg, Germany. Figure 8 shows the apartments during construction. For the assembly of the elements Eltomation supplies small hand operated equipment as well as the fully automatic computer operated DUOTEC assembly line (Van elten, 2000).

2.7 Advantages and disadvantages of cement bonded board

2.7.1 Advantages

There are different types of cement bonded board and have several advantages over using other boards. We can point out the advantages in following way: Cement bonded boards are strong, stiff and resistance to moisture, fungi and insect. Fire resistance is being higher than any other boards. In panel form, they are being utilized for structural and nonstructural application in both exterior and interior purpose. It reduces thermal conductivity and increase sound insulation. An added advantage over massive concrete panels is their ability to withstand larger deformation before failure. Present world is very much concern about environmental pollution. All formaldehyde-based resin binders are more or less toxic to the environment; it is free from formaldehyde, isocyanides, wood preservatives, fungicides (Kayode, 2007). It can be produced by either labor-incentive or machine incentive operation, which is most economically feasible. It can be used as erection of free standing solid partition, various sound damming partition construction. It is easy to cut to size service fabrication prior to site. It is easy to fix, it is frost resistance, it can be panned, sanded, drilled, routed, screwed and primed. It is biologically safe. It can be disposed of on a landfill site. It can be decorated with different finishes which is helpful to diversify its uses. It is moisture proof and for this it can be used in damp condition. It is paintable which is helpful to design with our own requirements (Atchison, 1985; Hofstrand *et al.*, 1984; Kimura *et al.*, 2001; Kawai, 1999; Rowell, 1997; Rowell, 1998; Youngquist *et al.*, 1996; Zhang *et al.*, 1997).

2.7.2 Disadvantages

Although cement bonded board is highly promising in construction, furniture and others paneling, it has some disadvantages:

High density: For high density it is very difficult to handle in manufacturing and use. Need more transportation cost and cannot used in light constructions like furniture. Due to high density heavy weight per square foot that lead several Problem in installation and application. Handling by one person is difficult. Need extra labor and machineries during installation (Sotannde, 2010).

Long curing time: For long curing time manufacturing process is more complex and time consuming. Need extra care and attention in hydration process of cement. Need more labor. Long curing time causing obstacles for commercial production

Water absorption capacity: Cement bonded board shows a high-water absorption capacity. If board absorbs more water it makes heavier per square foot. Further in the case of woody and other lignocellulosic cement bonded board, water makes the board weaker as they are hygroscopic in nature. We can point out some more disadvantages associated with cement bonded board those are; Cutting of cement board must also be done with carbide-tipped tools and saw blades. Due to its hardness, pre-drilling of fasteners is often recommended. Finally, cement board is initially more expensive than other board (Markessini *et al.*, 1997; van Elten, 2013; Eusebio and Kawai, 1999; (Miyatake *et al.*, 1998); Rowell, 1998; Youngquist *et al.*, 1996; Zhang *et al.*, 1997

3 Materials and methods

3.1 Raw materials collection and preparation

In this research, agricultural wastages jute sticks were used as raw material. These raw materials 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 1-2 m long and 5-10 mm 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 mm and 1 mm were used to obtain the jute stick particles which passes through the 2 mm mesh and was retained by the 1 mm mesh. Then the particles were spread out in rows 2 to 4 inches deep under ambient room conditions (approx. 25°C)

Jute sticks were cut into smaller size having average length of 2-3mm.the jute sticks were also dried under ambient room conditions (approx. 25°C).

Ordinary port land cement was selected for cement bonded board (CCB). Ordinary Portland cement was bought from local market, stored in air tight pack till the time it was used. Some chemical additives like $CaCl_2$, $MgCl_2$ were used to accelerate curing of cement or using pretreatments such as aqueous extraction to remove inhibitory substances from wood, CO_2 treatment etc.

There are different types of pozzolan materials (Rice husk, silica fume) and chemical additives were used for reduce the curing time and to modify the lignocellulosic particles. The most effective additive is calcium chloride because it reduces the hydration time of wood–cement boards to just 3 h compared to around 9 h for boards containing no additive (Eusebio and Cabangon, 1997a, b). So, $CaCl_2$, $MgCl_2$ were used in the manufacturing process of CBPB to introduce faster setting cement bonded composite materials.

Distilled water in specific ratio with cement (1:2) was used as the curing agent of OPC. Rice husk showed excellent properties in a ratio of 10% by weight of cement. Therefore, rice husk was used as a potential source of raw material for manufacturing of cement bonded particleboard.

The dimensions of the boards were 25×25cm. The weight of the particles was measured according to their target process and particles are hand-formed (using a forming box) into homogenous single-layer mats. The mats then pre-pressed and again pressed with a cold/hot pressing machine which required. To test the effect of pressing temperature conditions, pressing time, curing time and water absorption capability.

3.2 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 ratio of cement, reinforcement particles and water (2.2:1:1.1 (w/w/w)) was followed for the manufacturing of all types of boards. Control board was produced using jute sticks particles as the only reinforcing material. Then Rice husk ash (RHA) was also added (10%) as pozzolanic materials in CBPB which was replaced with cement. $CaCl_2$ and $MgCl_2$ were added 1.5% and 2% concentrations respectively.

3.3 Particleboard manufacturing

The particleboards were produced at the Wood Processing laboratory of Forestry and Wood Technology Discipline, Khulna University. All the raw materials (OPC, jute stick particles, $CaCl_2$ and $MgCl_2$, RHA 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 stick particles were mixed together. Then chemical additives ($CaCl_2$ and $MgCl_2$) were added and blended with water for about 6 minutes to get a uniform mixture of all the components. The mixture was placed in aluminum caul plate using a forming box to form standardized mat. During heating and pressing the mat, Aluminum 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 curing.

For curing of cement, water was sprayed frequently during 3 days, 5 days, 7days and 9 days experiment. At least three replications of each type of board were performed to produce boards having dimension of 35×35×.7cm approximately. The manufactured boards were trimmed and put into room temperature for 24 hours before testing of properties.

Table 2. Types of board produced in this experiment.

Type of board	Raw Materials (Ratio) (C:P:W-2.2:1:1.1)			(%)	(%)	(%)	Pressing time	Pressing Temperature	Conditioning condition
	Cement (g)	Jute stick particle(g)	Water (g)	$CaCl_2$	$MgCl_2$	RHA			
Control (Cement and jute stick particle)	300	145	150	-	-	-	24hours	5MPa	24hours conditioning at (approx. 25°C)
Type 1 (Cement, Jute stick particle and $CaCl_2$)	300	136	150	2%	-	-	24hours	5MPa	24hours conditioning at (approx. 25°C)
Type 2 (Cement, Jute stick particle and $MgCl_2$)	300	136	150		1.5%	-	24hours	5MPa	24hours conditioning at (approx. 25°C)
Type 3(Cement, Jute stick particle, $CaCl_2$ and RHA)	270	136	150	2%		30	24hours	5MPa	24hours conditioning at (approx. 25°C)

3.4 Determination of physical properties

All the samples were cut into 5 cm × 5 cm. for testing physical properties. The laboratory test for characterization of physical properties was carried out in the laboratory, Forestry and Wood Technology Discipline, Khulna University. At first the samples were weighted and green dimension were taken at room temperature. Then the samples were submerged into water for 2 hours. Then the wet weight and dimension was taken and all the properties were calculated by using formula. Then the samples were again submerged into water for 24 hours. Then finally, wet weight and dimension was taken and all the properties were calculated by using formula.

3.4.1 Density

Density (D) of each board was calculated after measuring weight and volume using the following equation-

$$D = \frac{m}{v}$$

Where m is the mass and v is the volume of each sample.

(Desch and Dinwoodie, 1996)

3.4.2 Water absorption

The water absorption (A_w) and thickness swelling (G_t) were determined by soaked in water for 24 hours. The water absorption and thickness swelling rate were increased with the time passed. After 2 hours and 24 hours the water absorption and thickness swelling were calculated by an electric balance and a digital slide caliper as a percentage.

Water absorption was calculated by the following formula-

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

Where m_1 is the weight of the sample before immersion and m_2 is the weight of the sample after immersion in water.

3.4.3 Thickness swelling

Thickness Swelling was determined by using the following equation-

(ASTM, 1997)

$$G_t = \frac{t_2 - t_1}{t_1} \times 100$$

Where t_1 is the sample thickness before immersion and t_2 is the sample thickness after immersion into water.

3.5 Determination of mechanical properties

All mechanical properties evaluation was carried out in the laboratory of Forestry and Wood Technology Discipline of Khulna University of Khulna, Bangladesh. The Malaysian standard 'Specification for Wood Cement Boards', MS 934:1986 was followed to evaluate the both physical and mechanical properties.

3.5.1 Modulus of rupture (MOR)

The MOR was calculated by Equation 1.

$$MOR = \frac{3PL}{2bd^3} \quad \text{……Eq.1}$$

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).

3.5.2 Modulus of elasticity (MOE)

The MOE was calculated by Equation 2.

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

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

3.5.3 Internal bonding

Many methods have been developed to measure the IBS of boards. These methods are based on tensile, shear or even dynamic loading and the IBS can be determined in terms of strength, energy or modulus. IB test was done in Akij Particle Board Mills Limited, Manikgonj, Dhaka.

3.5.4 Compressive strength

The compressive strength perpendicular to the grain varies between 12-18% of that parallel to the grain. The compressive stress at the proportional limit, for loading perpendicular to the grain, is about 12-25% of that for loading parallel to the grain. In dry condition, lumber can possess significantly higher compressive strength. Compressive strength of board was tested in Akij Particle Board Mills Limited, Manikgonj, Dhaka.

3.6 Analysis of data

All the data, produced during the laboratory tests for characterization of physical and mechanical properties of each type of fiber boards, were analyzed by using Microsoft Office Excel 2016 and SPSS) software. ANOVA (Analysis of Variance) and Tukey's HSD (honest significant difference) were conducted to analyze the data ($\alpha \leq .05$).

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.

4.1.1 Density

Mean values of CBPB densities are shown in figure 10. 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 Ca-9(calcium chloride treated board after 9th days) and Ca+RHA-9(calcium chloride and rice husk treated board after 9th days) were the lowest. This might occur because of efficacy of $CaCl_2$ as an excellent curator and with the combination of RHA it would give better result.

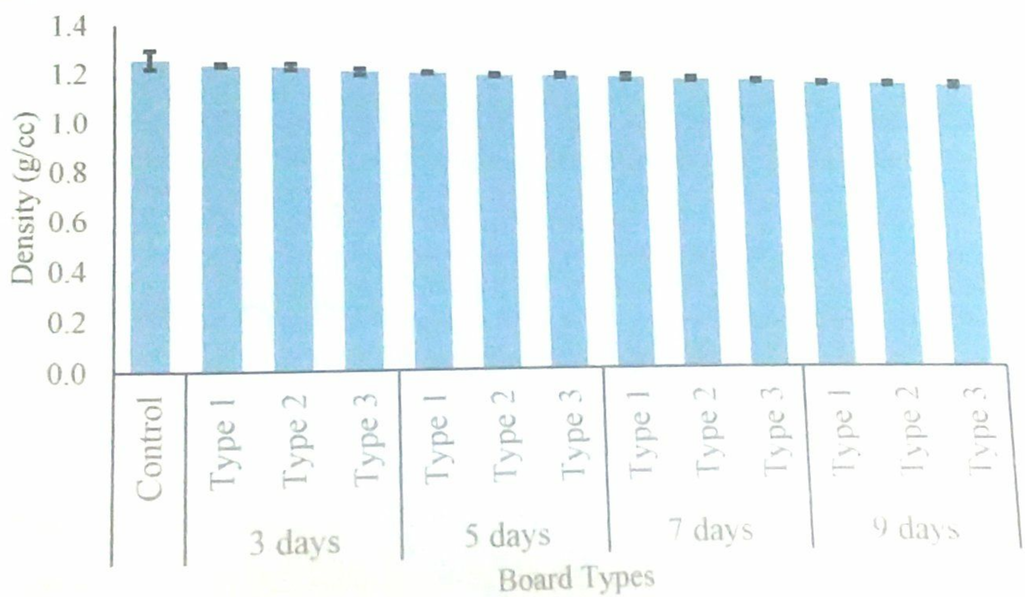

Fig.10. Density of different types of cement bonded boards.

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. In comparison to different literature regarding cement bonded particleboard like (Agarwal,2008) the density values ranged between 1.06 and 1. 28g/cm^3, i.e., 1060-1280Kg/m^3 while the moisture content ranged between 4.0 and 11.6%. The density of all the composite samples exceeded the minimum value of 1000Kg/m3 stipulated in ISO 8335 (1987) for cement-bonded composites. Expectedly, there was a general increase in density with increase in cement content. While the addition of $CaCl_2$ contributed to a slight increase in the density of the composite samples, while the addition of NaCl did not. Analysis of variance (ANOVA) also showed that the addition of both $CaCl_2$ and NaCl as chemical accelerators resulted in a significant increase in the moisture content of the composite samples. This was expectedly due to the well -known water retention property of both salts. The positive implication of the water retention is that cement hydration would be enhanced.

The density of 7 days and 9 days chemically cured boards were comparatively better in relation to the control one because the control board was cured in 28 days where our desirable result came in around 10 days when the conditions were applied. Type 1 and Type 3 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 11.

Water absorption rate decreases when Calcium chloride is used. Water absorption after 24 hours of controlled board is 24.37 where Type 1 (calcium chloride treated board after 9th days) and Type 3 (calcium chloride and rice husk treated board after 9th days) were 18.63 and 16.75 respectively. This is positive effect in comparison to control board which is cured for 28 days.

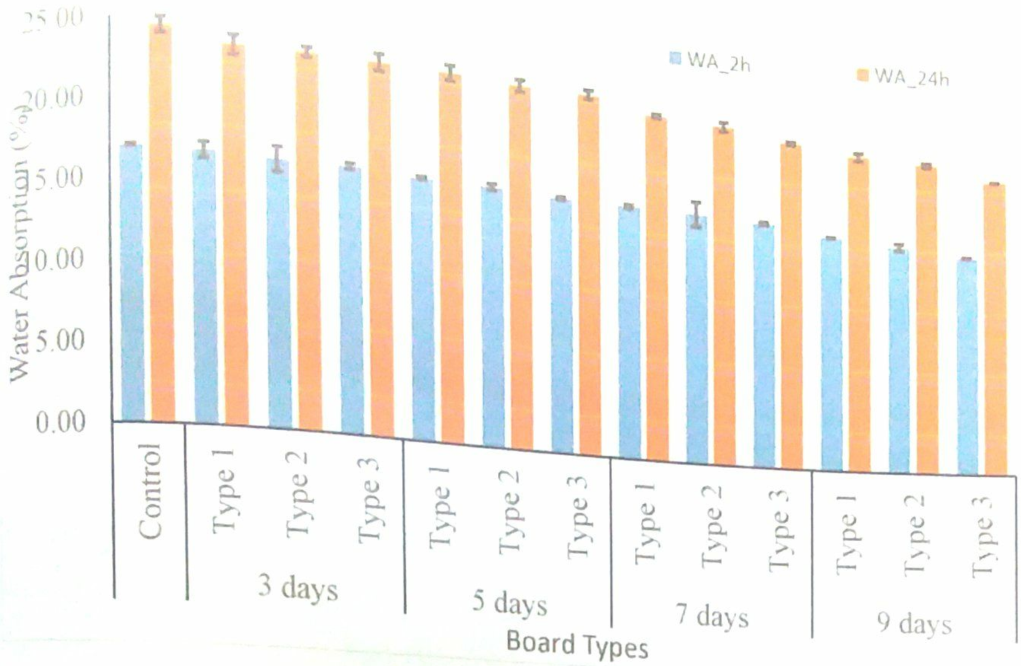

Fig. 11. Water absorption (%) of different types cement bonded boards.

Elsaid *et al.* (2011) 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.

Aggarwal *et al.* (2008) 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. The test results for WA at 1 hour and 24 hours respectively are presented in (Ajayi,2006) showed that WA values ranged between 15.0 and 38.8% and between 24.1 and 46.1% after 1h and 24h of immersion respectively. It is clear from the 1 H test results that the cement-bonded rattan composite samples had a relatively high-water absorption capacity and may therefore not be installed outdoors. The control (untreated) samples exhibited the highest WA, regardless of the rattan- cement ratio, perhaps due to their relatively low moisture content and the presence of more void spaces within the composite. The $Cacl_2$-treated samples generally absorbed less water than the and NaCl-treated samples, particularly at 4% level of concentration. 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 12.

Thickness swelling (TS), as an important attribute concerning dimensional stability, is highly correlated with the cement-wood ratio. In general, a higher cement content of a board lowers TS. It seems that the embedding of wood inside CBCs restricts expansion (Moslemi and Pfister,1987). In order to minimize TS, with the negative side effect of decreased MOR, reducing cement-wood ratio is a possibility whereby water absorption is also decreased (Meneéis *et al.*, 2007). Increasing cement coating on the particles may have a positive effect on TS (Eusebio *et al.*, 2000b).

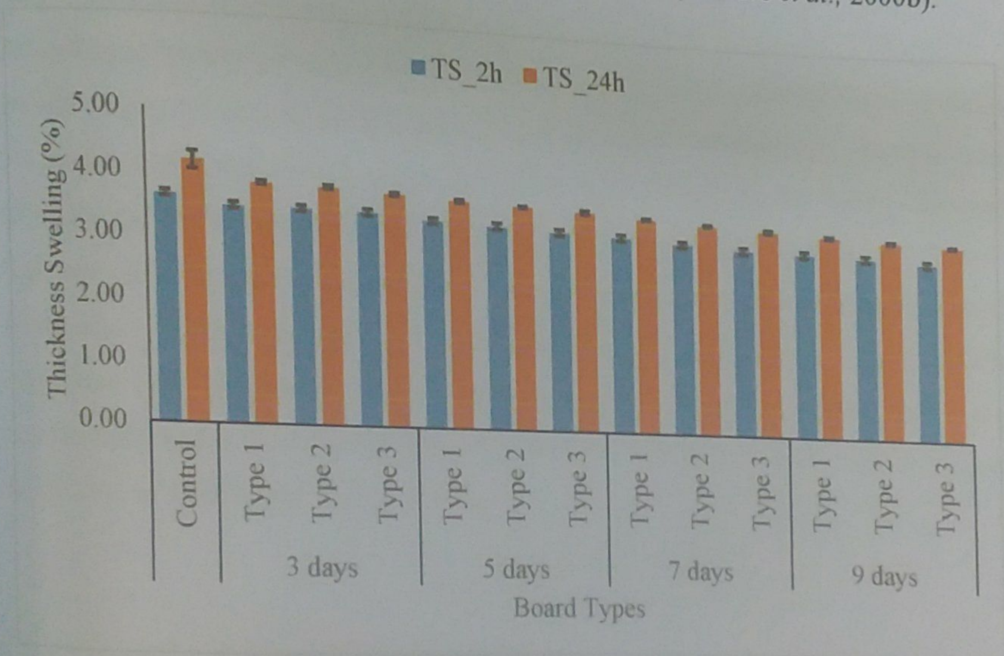

Fig. 12. Thickness swelling (%) of different types of cement bonded boards.

Also, chemical additives can decrease TS. By using $CaCl_2$ as an accelerator, TS could be reduced. This improvement is explained by better fiber to fiber contact as a result of improved bonding ability with cement. Besides $CaCl_2$ also hot water soaking or $MgCl_2$ treatment are effective methods to reduce TS (Semple and Evans, 2004).

Type 2 (Magnesium chloride treated board after 7^{th} days) and Type 3 (calcium chloride and rice husk treated board after 9^{th} days) show lower TS compared to others and control board also. In comparison to other opinion on literature regarding cement bonded particleboard, thickness swelling of 7 days and 9 days chemically cured boards were comparatively lower in relation to the control one because the control board was cured in 28 days where our desirable result came in around 10 days when the conditions were applied.

4.2 Mechanical properties

The mechanical properties of modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding (IB), and surface soundness (SS) were studied at 95% significance level.

4.2.1 Modulus of elasticity (MOE)

According to general properties of low-density cement wood composites in a specific gravity range, 0.5 to 1.0, the modulus of rupture was 1.7 N/mm2 to 5.5 N/mm^2 and the modulus of elasticity 621 N/mm^2 to 1241 N/mm^2 (Wang and Xu, 1994). The data of MOR and MOE obtained in this study satisfies the specified property and Type 1 (calcium chloride treated board after 7^{th} days) and Type 3 (calcium chloride treated board after 9^{th} days) showed significant results after 9 days as they compared with controlled one. The results obtained for the MOR of the panels in this study were significantly lower than the European standard (>9 N/mm^2) when the density ranges from 1200 to 1300 kg/m^3 (Anon., 1996).

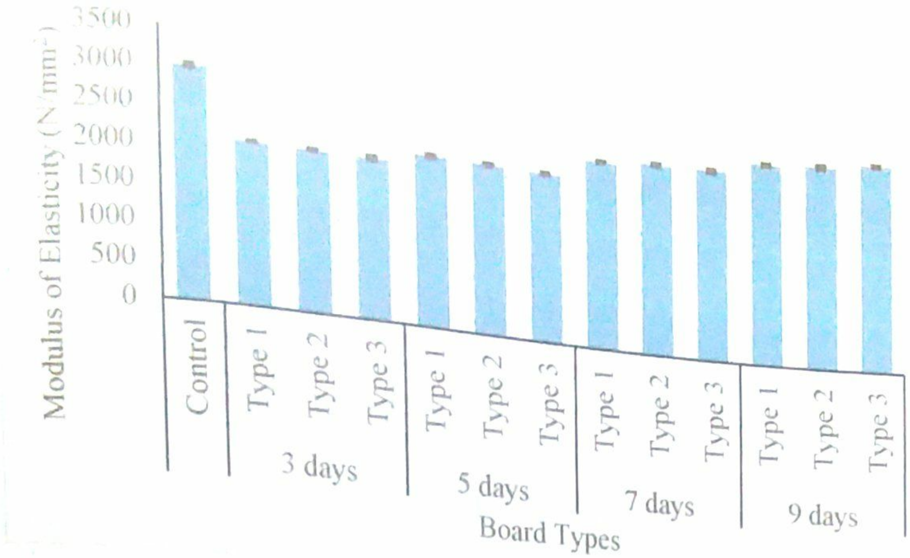

Fig. 13. MOE values of different types of cement bonded boards.

(Olorunnisola,2005) 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.

Nurhazwani *et al.*, (2016) 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.

In comparison to different cement bonded particleboard, MOE of 7 days and 9 days chemically cured boards were 2403 and 2806 MPa comparatively better in relation to the control one's 3577 MPa because the control board was cured in 28 days where our desirable result came in around 10 days when the conditions were applied.

4.2.2 Modulus of rupture (MOR)

Variation of the mean values of MOE is shown in Figure 14. A remarkable increment of MOR was observed in case of Calcium treated boards after 9 days. Type 3 showed best performance of MOR after treatment period. The MOR of Type 3 is 8.17 which is too close to 28 day's control board (9.48). The most significant result was noticed in case of rice husk coarse board. It exceeded 6 N/mm^2. It is reported that the MOR value was 9-13 N/mm^2 in wood cement particleboard at the target density of 1200 kg/m^3 (Hermawan, 2001). The MOR was 3.90 and 4.01 N/mm^2 in cement bonded particleboard from pine (Pinus pinaster A it) in a cement and wood ratio of 85:15 and 80:20 with a density of 1630 and 1460 kg/m^3 respectively (Pereira et al., 2004). Variation of the mean values of MOR is shown in figure.

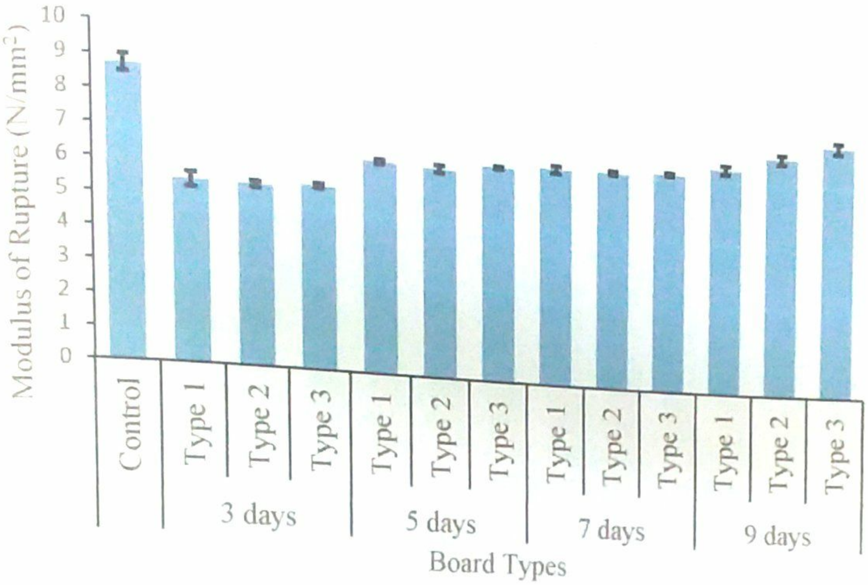

Fig. 14. MOR values of different types of cement bonded boards.

The MOR was 3.83 and 5.80 N/mm^2 in cement bonded blue gum (*Eucalyptus globules* Labil) particleboard in a cement and wood ratio of 85:15 and 80:20 with a density of 1630 and 1460 kg/m^3 respectively. The MOR of bamboo-cement board with a density of 890 kg/ m^3 was 8 N/mm^2 (Anon., 1996). Compared to bamboo-cement board, the MOR of cement-bonded rice husk board and saw dust board was comparatively lower.

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.

In comparison to experts and authors regarding cement bonded particleboard, MOR of 7 days and 9 days chemically cured boards were comparatively better in relation to the control one because the control board was cured in 28 days where our desirable result came in around 10 days when the chemical treatment by $CaCl_2$ and rice husk ash were applied.

4.2.3 Internal bond (IB)

Variation of the mean values of IB is shown in Figure 15. Found similar pattern as the results for other mechanical properties. Treatment with Calcium and magnesium chloride gradually reduced the IB of the produced CBPB (df=6, F=96.2, $P<0.05$).

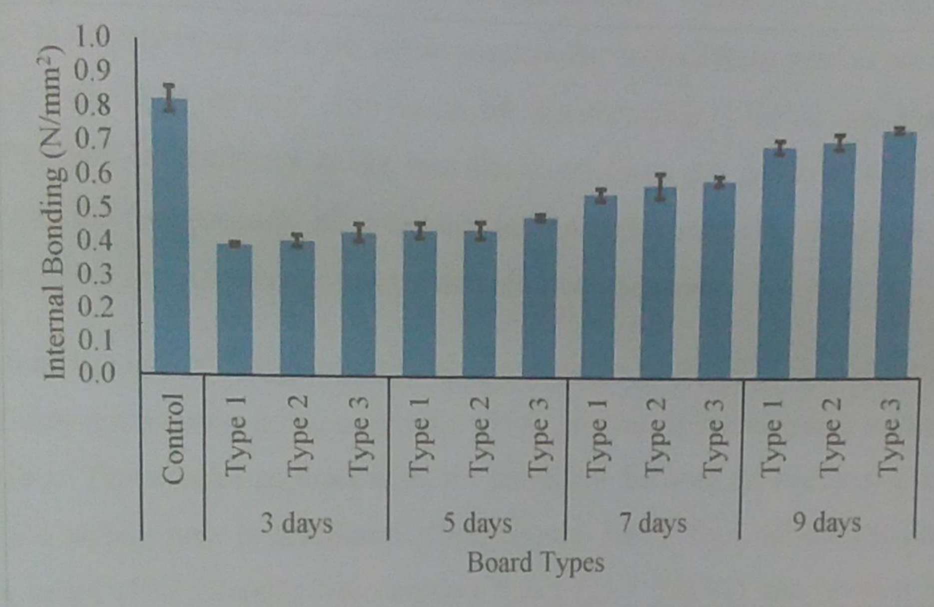

Fig.15. IB values of different types of cement bonded boards.

But, mixture of calcium chloride and Rice husk after 7 days and 9 days showed significant results .566 and .78 in IB where in 24 days IB of control board is 1.03.

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.

In comparison to control board, internal bonding of 7 days and 9 days chemically cured boards were comparatively better in relation to the control one because the control board was cured in 28 days where our desirable result came in around 10 days when the conditions were applied.

4.2.4 Compressive strength

Typically, the compressive strength (parallel and perpendicular to the grain) increases an average 4-6% for every 1% decrease in moisture content. The compressive strength of the boards varied significantly depending on the type of wood particle, w/c ratio and chemical additive used. The average compressive strength ranged from 12.55 N/mm^2 in flake boards to 15.16 N/mm^2 in flake-sawdust boards. These values fell short of the compressive strength of neat cement. According to Gong *et al.*, (2004) the compression strength values required for material to be used as pavements ranged from 20-25 N/mm^2. The reason for this according to Bentur and Mindness (1990) could be attributed to the fact that wood fibres are generally not used to improve the compression of wood-cement bonded composite, though a small improvement in strength may sometimes result from their use.

The high strength of flake-sawdust composite could be attributed to the distribution of the flakes and sawdust in the composite which eliminate the void spaces as much as possible. This became apparent when the interaction between the chemical additives and the mixing ratio is considered (Olorunnisola, 2007). Thus, all the composites; flake board (19.9 N/mm2) flake-sawdust board (24.7 N/mm2) and sawdust board (23.3 N/mm2) compared favorably with cement composites used for pavements when the w/c ratio was increased to 1: 3.5.

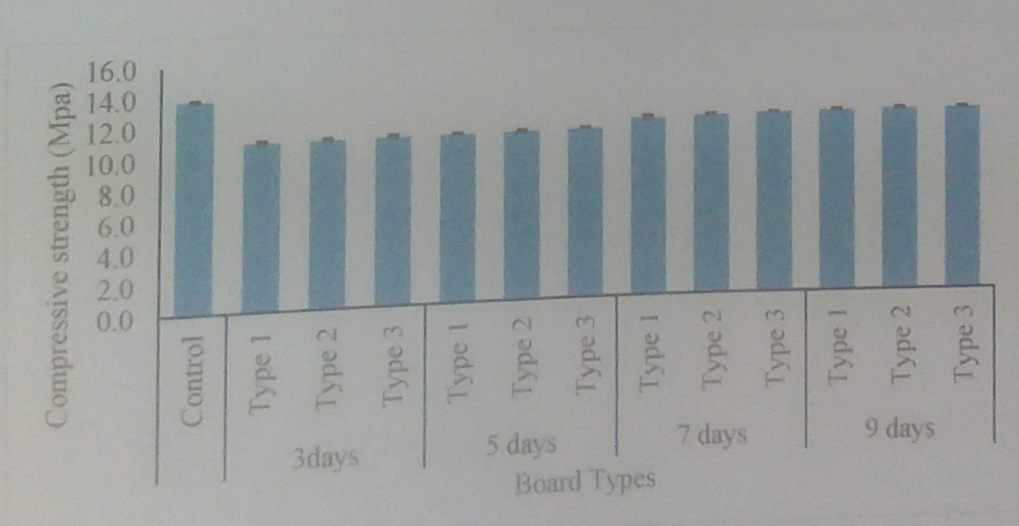

Fig.16. Compressive strength of different types of cement bonded boards.

In comparison to control board, compressive strength of 7 days and 9 days chemically cured boards were comparatively better because the control board was cured in 28 days where our desirable result came in around 10 days when the conditions were applied.

5 Conclusion

According to the results found in this study, curing time of CBPB, which is presently one of the major problems can be minimized significantly by using chemical additives such as calcium and magnesium chloride along with rice husk. 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. The physical and mechanical properties of cement-bonded particleboards were e valuated by chemical accelerators ($CaCl_2$, $MgCl_2$ and rice husk ash. From the quality view point, board produced with the combination of $CaCl_2$ and rice husk had the best influence on the setting of the boards followed by $MgCl_2$ and $CaCl_2$ respectively than boards produced without any chemical additive. Generally, it takes almost 28 days for curing of cement but this study stated that the curing time can be minimized into 10-14 days with the use of chemical additives because in 9 days experiment the physical and mechanical properties results were very good and close to the result after 28 days curing.so it can save the time and also it can be helpful and a good sign for industrial purposes.

Anon. 2001, The application of carbon dioxide- curing technology on the manufacture of the oil palm fronds cement-bonded board. *Department of Forest and Biomass Science*, Graduate School of the Faculty of Agriculture, Kyoto University, Kyoto, 47–80.

Badejo, S.O.O., Omole, A.O., Fuwape, J.A. and Oyeleye, B.O. (2011). Static bending and moisture response of cement bonded particle Board Produced at different levels of percent chemical additive content in Board. *Nigerian Journal of Agriculture, Food and Environment*, 7(4): 111-120.

Bakharev, T. (2005). "Geo polymeric materials prepared using Class F fly ash and elevated temperature curing." *Cement and Concrete Research, 35(6)*, 1224-1232.

Bietz, H., and Uschmann, W. (1984). "Zum Verfestigungsverhalten von Holz-Zement-Verbunden beim Einsatz von Holzresten," *Holztechnologie* 25(3), 116-118. (In German)

Brasileiro, G.A.M., Vieira, J.A.R. and Barreto, L.S. (2013). Use of coir pith particles in composites with Portland cement, *Journal of environmental management*, 131: 228-238.

Chen, F.W., Kasim, J. and Chew, L.T. (1991). Particleboard from bamboo (*Bambusa vulgaris*), *FRIM Reports*, 56: 35-44.

Clemons. 2001, Wood-Plastic Composites in the United States. *Forest Product Journal.*, Vol 52. No.6.

Datye, K. R., and Gore, V. N. (1998). "Innovative designs of wood-bamboo-brick composites," *5th World Conference on Timber Engineering*, Montreux, Switzerland, 526-533.

Del Menezzi, C.H.S., Castro, V.G. and Souza, M.R. (2007). Production and properties of a medium density wood-cement boards produced with oriented strands and silica fume. *Maderas. Ciencia y tecnología*, 9(2): 105-115.

Del Menezzi, C.H.S., Ribeiro, R.B., Sternadt, G.H., Teixeira, D.E., Okino, E.Y.A. (2008). Effect of thermal post-treatment on some surface-related properties of oriented strand boards. Drvna Industrija 59(2), 61-67.

Desch, H.E. and J.M. Dinwoodie, 1996. Timber: Structure, Properties, Conversion and Use. 7th Edn., Food Products Press, London, UK., ISBN: 9781560228615, pp: 102-127.

Eusebio, D.A. and R.J Cabangon, (1997a). Hydration temperature of cements containing various cement- setting accelerators. Official travel report. Forest Products Research and Development Institute, Department of Science and Technology, college, Laguna, Philippines.

Eusebio, D.A. (2003). Cement bonded board: Today's alternative. Technical Forum in celebration of the PCIERD 21st anniversary. Pasig City, Phillipine, 23 – 45.

Eusebio, D.A. and R.J. Cabangon (1997b). Manufacture of wood-wool cement boards using Australian-grown wood species. Official travel report. Forest Products Research and Development Institute, Department of Science and Technology, college, Laguna, Philippines.

Falk, R. H., (1994). Building products from recycled wood waste. In: *Proceedings*, 12th annual Excellence in housing conference and exposition. Dallas, USA, TX: Wausau, WI: Energy Efficient Building Association: E1-E6, 23-26 February, 1994.

Hermawan, D., Hata, T., Kawai, S., Nagadomi, W., and Kuroki, Y. (2002a). "Effect of carbon dioxide-air concentration in the rapid curing process on the properties of cement-bonded particleboard," *J. Wood Sci*. 48, 179-184.

Islam, M.S., Das, A.K., Ahmed, M.K. and Shams, M.I. (2013). Effects of $CaCl_2$ and $NaHCO_3$ on the physical and mechanical properties of Dhaincha (*Sesbania aculeata*) cement-bonded particleboard, *Journal of the Indian Academy of Wood Science*, 10(2): 81-85.

Jorge, F. C., Pereira, C., and Ferreira, J. M. F. (2004)," Wood-cement composites: A review." Holz Roh Werkst. 62, 370-377.

Kasai, Y., Kawamura, M. and Zhou, J.D. (1998). Study on wood chip concrete with used timber, *Special Publication*, 179: 905-928.

Kayode, J. (2007). Conservation implication of timber supply pattern in Ekiti State, Nigeria. Research Journal of Forestry, 1(2), 86-90.

Markessini, E., Roffael, E. and Rigal, L. (1997). Panels from annual plant fibers bonded with urea-formaldehyde resins, in *Proceedings 31th International Particleboard/Composite Materials Symposium, Pullman.*

Markessini, E., Roffael, E., and Rigal, L. (1997). "Panels from annual plant fibers bonded with urea-formaldehyde resins," in: *Proceedings of the 31th International Particleboard/Composite Materials Symposium,* Pullman, Washington, 147-160.

Matsushita, Y., Miyawaki, S. and Yasuda, S. (2003). "Manufacture of wood-cement boards VIII: cement-hardening inhibitory compounds of keyaki (Japanese zelkova, Zelkova serrata)," *Journal of Wood Sci.*, 49: 281-284.

Miyatake, A., Fiujii, T., Hiramatsu, Y., Abe, H. and Tonosaki, M. (2000). Manufacture of wood strand-cement composite for structural use: wood cement composites in the Asia Pacific Region, Canberra, Australia, 148 – 152.

Moslemi, A. A. (1988). Wood-cement panel products: coming of age. In: *Proceedings* 1st. International Conference on Fiber and Particleboards Bonded with Inorganic Binders. Moscow, ID, USA. 2426 October 1998, 2-18.

Nemli, G.; Aydin, A. 2007. Evaluation of the physical and mechanical properties of particleboard made from the needle litter of *Pinus pinaster* Ait. *Ind Crops Prod* 26(3): 252-258.

Ntalos, G. and Papadopoulos, A. (2006). "Mechanical and physical properties of cement bonded OSB." *Cost Action E44 - E49 Wood Resources and Panel Properties*, Valencia, 315-319.

Ohnishi, K., Okudaira, Y., Zhang, M. and Kawai, S. (2000). Manufacture and properties of oriented medium density fiberboard from non-wood lignocellulosic fibers, 1: Development of a mechanical orientor and its application to manufacturing oriented fiberboard, *Journal of the Japan Wood Research Society (Japan)*.

Okino A.A.S.Y., Evans. J.K. and Cloutier, A. (2004). Some properties of bamboo-cement board, *In Proceedings of the 1st International Wood Science Seminar*, Kyoto, Japan, 83-91.

Olorunnisola, A.O. (2007). Effect of particle geometry and chemical accelerator on strength properties of rattan-cement composites. *African Journal of Science and Technology*., 8: 22 - 27.

Papadopoulos, A.N., Ntalos, G.A. and Kakaras, I. (2006). Mechanical and Physical properties of cement-bonded OSB. *HolzRohWerkst.*, 64: 517 - 518.

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): 273-278.

Semple, K.E.; and Evans, P.D. (2004). Wood-cement composites: Suitability of Western Australian mallee eucalypt, blue gum and melaleucas. RIRDC Publication.

Simatupang, M. H. and Habighorst, C. (1992). "The carbon dioxide process to enhance cement hydration in manufacturing of cement-bonded composites - comparison with common production method," *3rd International Inorganic-Bonded Wood and Fiber Composite Materials*, Spokane, Washington, USA, 114-120, 1992.

Simatupang, M. H. and Habighorst, C. (1993a). "Fertigung und Eigenschaften von schnell abbindenden, zementgebundenen Probekörpern und Spanplatten, hergestellt durch Begasung mit Kohlendioxid - Stand der Forschung und Entwicklung," *Holz Roh Werkst.* 51, 31-35. (In German)

Simatupang, M. H. and Habighorst, C. (1993b). "Fertigung und Eigenschaften von schnell abbindenden, zementgebundenen Probekörpern, hergestellt durch Begasung mit Kohlendioxid," *Holz Roh Werkst.* 51, 107-114. (In German)

Simatupang, M. H. and Habighorst, C. (1993c). "Fertigung und Eigenschaften von schnell abbindenden, zementgebundenen Spanplatten, hergestellt durch Begasung mit Kohlendioxid," *Holz Roh Werkst.* 51, 247-252. (In German)

Simatupang, M. H. Habighorst, C., Lange, H., and Neubauer, A. (1995). "Investigations on the influence of the addition of carbon dioxide on the production and properties of rapidly set wood-cement composites," *Cement Concrete Comp.* 17, 187-197.

Simatupang, M. H. Seddig, N., Habighorst, C., and Geimer, R. (1991). "Technologies for rapid production of mineral-bonded wood composites boards," *For. Prod. Res. Soc. 2*, 18-27.

Sotannde, O.A.; Oluyege, A.O.; Adeogun, P.F.; and Maina, S.B. (2010). Variation in wood density, grain orientation and anisotropic shrinkage of plantation grown *Azadirachta Indica. Journal of Applied Sciences Research,* 6(11), 1855-1861.

Sudin, R. and Swamy, N. (2006). Bamboo and wood fiber cement composites for sustainable infrastructure regeneration. *Journal of Materials. Science,* 41(21): 6917-6924.

Van Elten, G.J. (2013). Wood strand cement boards with a practically closed surface and production process, Google Patents.

Wang, S.Y.; Yang, T.H.; Lin, L.T.; Lin, C.J.; Tsai, M.J. 2008. Fire retardant treated low formaldehyde emission particleboard made from recycled wood waste. *Bioresour Technol* 99: 2072-2077.

Wolfe, R. W. and Gjinolli, A. (1996b). "Cement-bonded wood composites as an engineering material," *The Use of Recycled Wood and Paper in Building Applications*, Madison, Wisconsin, 84-91.

Yazici, H.; Aydin, S.; Yigiter, H.; Baradan, B. (2005). "Effect of steam curing on class C high-volume fly ash concrete mixtures". *Cement and Concrete Research*. 35: 1122.

Young, J. F., Berger, R. L., and Breese, J. (1974). "Accelerated curing of compacted calcium silicate mortars on exposure to CO_2," *J. Am. Ceram. Soc.* 57(9), 394-397.

Zheng, Y. Pan, Z. Zhang, R. Jenkins, B.M. and Blunk, S. (2006). Properties of medium-density particleboard from saline Athel wood, *Industrial Crops and Products*, 23(3): 318–326.