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DEDICATED
TO
MY BELOVED PARENTS

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ABSTRACT

This paper reviews the research reported mostly in the last 30 years in the most common journals on the wood-cement composites field. The focused topics include: brief history and development of cement bonded boards, different types of cement bonded boards general manufacturing process of cement bonded boards, manufacturing process of most important types of cement bonded boards like, wood-wool cement board, cement bonded fiber board, cement bonded particle board, wood strand cement board. Also includes: raw materials and other chemicals used, the problem of the compatibility (or not) between cement and reinforcing materials like, wood, plastic, feather, glass etc., what causes it, ways of overcoming the problem; accelerators composition of cement bonded boards, their performance, application of cement bonded boards, advantages and disadvantages of cement bonded boards, present status of cement bonded boards. Present status and prospect of cement bonded boards in Bangladesh also presented.

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1 INTRODUCTION

1.1 Background of the Study

A cement board is a composite combination of cement and reinforcing materials. Lignocellulosic or non-lignocellulosic material's particles or fibers bonded together with Portland cement matrix is produced in panel form is called Cement bonded board. Its production and continuous research are becoming more prevalent in the number of countries around the world. Discovering new methods of manufacturing technologies to replace the traditional ones, expanding base, and modifying the inorganic binders are some of the aspects that are increasing in momentum (Aoki, 1991).

Wood is a lignocellulosic materials widely used for cement board production. Demand of wood is increasing day by day for their valuable various uses, Forest and other source for wood is decreasing day by day in an alarming rate. For this reason glass, plastic, feather etc. reinforcing materials are used for cement board production. The past decade has seen an increase in prefabrication of cement-bonded fiberboard around the world. Compared with conventional wood and other products, the cement fiberboard has higher fire resistance, moisture resistance, and better durability. Also, problems commonly related to wood like rot and insect attack are altogether eliminated. Further agricultural residues are used for cement board production. Residues are waste material, there is no valuable use, further if it is not dispose or manage in a good way it can impact negatively on environment. If we think about our country, wood is not available, forest area is very low and decreasing in a very alarming rate, where a large amount of agricultural residues are produced in every year and left without any used. So it can be very good source for cement bonded board production in our country.

The most apparent and widely used inorganic bonded composites are those bonded with Portland cement. Portland cement, when combined with water, immediately reacts in a process called hydration to eventually solidifying into a solid stone like mass. Successfully marketed Portland cement bonded composites consists of both low density products made with excelsior and high density products made particles or fibers (Youngquist, 1988). One of the most recent proposals for a research frame work on material science is to utilize bio based resource in the waste stream through the development of technologies that will produce composite products and composites.

In this context, it was cited that the major recycling opportunity to utilize wood wastes and agricultural wastes in future is to be blend proportionate amounts of materials with inorganic materials. For the inorganic materials, the most apparent and wide used example is cementing (Aoki, 1999).

Nowadays, environmental and economic concerns are stimulating research in the development of new materials for construction, furniture, packaging and automobile industries. Particularly, many research studies have conducted on composite panels from non-wood lignocellulosic materials in which most are based on natural renewable resources. These resources are abundantly available in many countries, including residues from annual growth crops and plants (Markessini et al., 1997; Rowell, 1998; Chow, 1994). Nowadays agricultural residues as well as other lignocellulosic non-lignocellulosic residues are getting importance in research works. These are almost waste materials and there is no significance use of these, sometimes used for fuelwood purpose. It has already showed good performance for making composites. Fibers have enough strength properties to bind with cement. Further Present world is very concerned about environmental pollution. All formaldehyde based resin binders are more or less toxic and injurious to health and both environment. Considering these aspects manufacture of cement bonded composites from saw dust and agricultural wastes are attempted (Stillinger and Wentworth, 1977). Uses of Agricultural wastes, other woody wastes from different sources, plastics, feather and other fibers wastes are not only reduced environmental hazard but also contributed to the economic growth of the country and also reduced pressure on existing forest.

The current major applications for cement-bonded fiberboard when substituting products in residential usage are for lap and panel siding, and simulated cedar shake and shingle products. Other potential uses are for slate roofing and flat panel applications including underlayment, tile backer board, and lumber substitutes as trim, fascia, and corner boards (Shao et al., 2001). The low density products may be used as interior ceiling and wall panels in commercial buildings. Low density composites bonded with Portland cement offers sound control and can be quite decorative. In some parts of the world, these panels function as complete wall and roof decking Systems. The exterior of the panel is stuccoes, and the interior is plastered. High density panels can be used as flooring, roof sheathing, load bearing walls, and cement forms. Fairly complex molded shapes can be molded or extruded, such as decorative roofing tiles or non-pressure pipes (Coutts, 1987).

1.2 Objective of the Study

One of the most over populated country is Bangladesh. The problem of housing is becoming more and more acute with the increase in its population. Moreover, natural disaster like flood is very frequent, and humid weather prevails in most part of the year. So there is need of making low cost housing materials. For these purpose mostly used construction and housing material is different types of cement bonded board (CBP). To get a clear overview of cement bonded board this review is conducted.

- To accumulate and gathering all information related to cement bonded boards and organizing and showing them in a harmonic way.

2 HISTORY AND DEVELOPMENT OF CEMENT BONDED BOARD

Mineral-bound wood-wool composites were already produced in the early 1900's created from spruce or popular wood-wool, using magnesite as a binder (Aro, 2004; Wolfe, 1999). In the 1920-ies, after the introduction of Ordinary Portland Cement (OPC), cement replaced the magnesite as a binder leading to the creation of wood-wool cement board (WWCB) (van Elten, 2006). The boards became increasingly popular because of their high thermal insulating and sound absorbing properties gained by the high porosity and low density (400-600 kg/m3). Consequently, because of the mineralization of the fibres, the boards possess high resistance to bio-degradation (Pereira et al., 2006) and fire (Aro, 2004). Hence, the boards are applied in both buildings and constructions as roof and ceiling material or as an exterior wall where a high durability and low maintenance is requested. In literature, the term wood-cement composites (WCC) are generally used to describe a composite made from wood, cement, water and in some cases additives. However, in this composite, there are different kinds of wood geometries used, leading to different kind of boards that are commonly referred to as "wood-strand cement board" (Aro, 2004), "cement-bonded-wood particle board" (Soroushian et al., 2003), "cement-bonded particle board" (van Elten, 2006), and "cement-bonded composite boards" (Aggarwal et al., 2008; Ashori et al., 2011).

Particleboards are not more than a few decades old production. Before particle board, modern plywood, as an alternative to natural wood, was invented in the 19th century, but by the end of the 1940's 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 1920's for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. The new technologies 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. 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 a phenolic resin. In the early 1960's, 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. The majority of research in this field has been carried out on particleboards and flake boards. An excellent review can be found elsewhere (Jorge et al., 2004).

Men developed composite wood products such as particle board, plywood, fiber board but they use mainly chemical resin as a binder. This chemical causes hazardous to human health. Even its load bearing capacity is not so good to use for building construction through it can be used for different type of furniture or decorative purposes. Considering that man is trying to find out the alternative which should not be harmful and bonding quality should be such that man can use it as building materials. All natural material is considered as environment friendly and cement is one of them. Environmental concern about the disposal of waste materials has focused renewed attention on low density cement bonded wood composites (CBWCs) (Moslemi, 1989).

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).

The industrial application of pressure to manufacture wood-cement panels did not occur until the about mid-1930s. With the gradual evaluation of resin bonded particle board technology, much was learnt that is also applicable to cement-bonded wood particle panels. Early industrial production of wood cement panels were produced in Japan in 1965 (Moslemi, 1989).

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 1959s, but it regained strength by the mid-1970s with the growing concern over the health risks linked to asbestos. The controversy over asbestos led a number of companies in Australia, Europe, and Scandinavia to develop processes for fabricating fiber-reinforced cement composites that use discrete fibers, including steel, glass, synthetic polymers, and cellulose (Moslemi, 1989). History of Industrial production of cement bonded board is shown in Table 1.

Table 1. Industrial production of inorganic bonded wood composites

Year	Product
1900	Magnesite bonded board
1905	Gypsum bonded excelsior board
1915	Gypsum Plasterboard
1915	Magnesite bonded excelsior board
1927	Cement bonded excelsior board
1937	Molded wood cement products
1942	Resin bonded particleboards
1965	Cement bonded wood composite panels
1972	Gypsum fibre boards
1972	Magnesite bonded wood composite panels
1982	Gypsum particleboard

(Kossatz et al., 1983)

Today, cellulose fiber is used in a wide variety of fiber-reinforced cement products, many of which were originally developed using asbestos fiber. These materials use only 5 to 15 percent cellulose fiber by weight, have densities ranging from 1,100 to 1,800 kg/m^3, and have bending strengths ranging up to 30 MPa. The primary function of fibers in these cement composites is to increase the energy of fracture. By bridging gaps, the fibers prevent stress concentrations at crack tips, thus retarding brittle fracture mechanisms and dissipating energy in the form of fiber pullout or rupture.

3 PRESENT STATUS OF CEMENT BONDED BOARD

A description of status of cement bonded board can be found; van Elten, (2013). Fig. 1 shows production of different types of cement bonded board in the world, and Fig. 2 shows the global distribution of the 90 cement board producers in the world. Europe has 38 producers, six of which are located in Germany and three are in Denmark. Significantly, a remarkably high number (15) are UK-based which is surprising given the low number of UK-based cement manufacturers. The Americas also have a large number (20) of cement board producers, most of which are located in North America, although Brazil and Chile do both have one producer each. In contrast, Asia, the Middle East and Africa have 22 producers between them. That China has only five cement board companies is quite surprising given its dominance in the cement industry. However, this quantity may increase rapidly over the next few years.

There are sure to be several companies around the globe their production is unknown in Fig. 2. Additionally, smaller privately-owned companies which supply cement board exclusively to domestic customers may also not be featured.

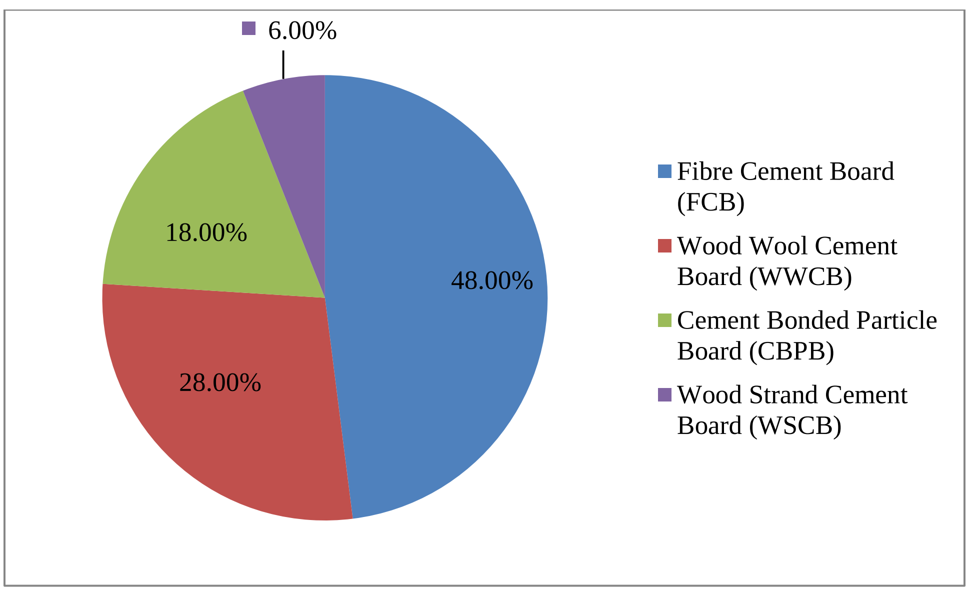


Fig. 1. Production of different types of cement bonded board in the world (Saunders and Davidson, 2014).

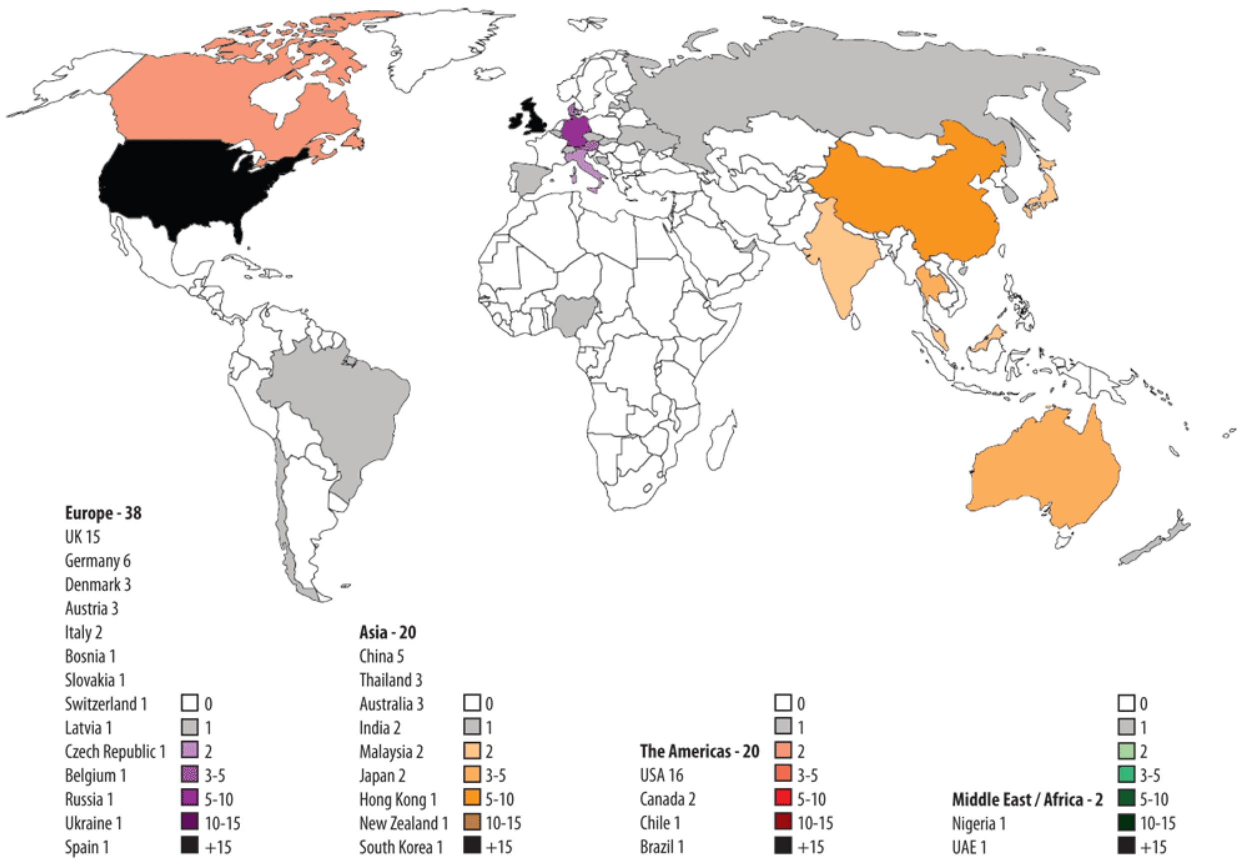


Fig. 2. Global status of cement bonded board producers (source: www.globalcement.com)

4 CLASSIFICATION OF CEMENT BONDED BOARD

There are several classifications of cement bonded board in several book and research paper. A classification of cement bonded boards is represented and can be found Fig. 3. Most of them are classified based on Raw materials used, manufacturing process involves. Furthermore someone classified it based on types of cement or other inorganic material like, Gypsum board, Magnesite bonded board etc.

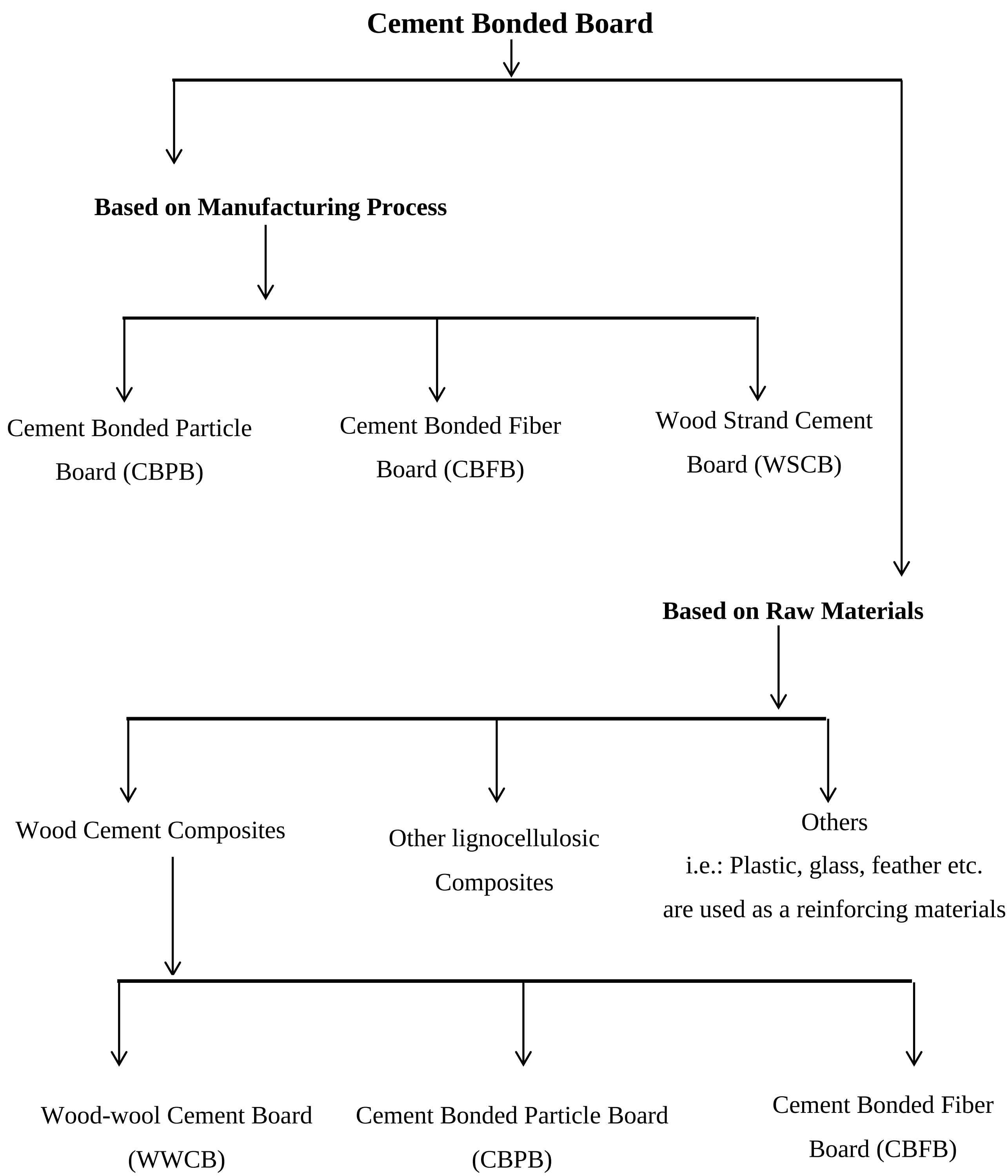


Fig. 3. Classification of cement bonded board

There are four important distinct categories of cement bonded board:

4.1 Fibre Cement Board (FCB)

Fibre cement board (FCB) also called Cement bonded fibre board (Fig. 4) has been used since the 1900s when Ludwig Hatschek first combined 90% cement and 10% asbestos fibres with water. The mixture was run through a cardboard machine to produce asbestos cement board. This board was widely used for residential construction until the 1970s discovery that asbestos cement board causes mesothelioma (a rare form of lung cancer), at which time many countries strictly prohibited its use. FCB is not only the oldest type of cement board, but also the most widely used and produced. It is manufactured by 43 companies worldwide, 48% of cement board producers (Tachi et al., 1889; Moslemi et al., 1889; van Elten, 2013; Saunders and Davidson, 2014).

Fibre cement board consists of cement, water, silica, limestone flour and fibres, can be they recycled, synthetic or cellulose pulp. Optional additives, including silica fume, metakaolin ($Al_2Si_2O_5$), fly ash, calcium silicate, flocculants (chemicals that promote coagulation) and defoamers may also be used (Joeckan, 2010).

4.2 Wood Wool Cement Board (WWCB)

Wood Wool Cement Board (Fig. 4) was initially developed in 1920 by Josef Oberleitner in Austria. It is manufactured by 25 companies worldwide, which is 28% of all of the cement board companies. European producers alone produce in excess of $20Mm^2$/yr of WWCB (Saunders and Davidson, 2014; Moslemi and Hamel, 1989).

WWCB comprises wood 'wool' fibres, cement, water, a salt solution and (optional) additives for property enhancements. Although individual recipes vary between companies, a general proportion of wood wool (by dry weight), cement and water of 1:2:1 is typical. The wood wool itself is made from softwood, usually industrially grown FSC pine, spruce, eucalyptus or poplar. The logs are felled, debarked and dried for several months to reduce the moisture and sugar content by natural fermentation. High sugar content inhibits the cement curing during manufacture. The wood is then shredded into fibres that measure 25 cm long, approximately 0.35mm thick and 1 - 5mm wide depending on the application of the finished board. In the USA wood wool is known as Excelsior (Anon, 2013).

WWCB is characterized by a very low density (350 – 570 kg/m^3). The low weight of WWCB enables easier handling and reduced-cost transport. WWCB is resistant to fire, moisture, wet and dry rot, vermin, termites and fungus (Tachi et al., 1889; Moslemi et al.,1889; van Elten, 2013; Saunders and Davidson, 2014).

4.3 Cement Bonded Particle Board (CBPB)

Cement Bonded Particle Board (Fig. 4) was first produced by Switzerland-based Durisol in 1970 under the trade name Duripanel. It was initially an extremely popular product due to the race to replace asbestos boards. While Durisol was originally one entity, it is now divided into region-specific companies, such as Durisol UK. Durisol is now a brand-name product that is sold world-wide by independent companies. CBPB is currently produced by 16 manufacturers around the world, which is 18% of world-wide cement board producers. Demand has not changed much since its initial entry onto the market.

CBPB is made from cement (60%), wood chip particulate (20% by dry weight) and water (20%). Small quantities of additives may also be added to improve cement setting times. The previous percentages are approximates only, as the actual recipe varies widely between companies. For example, Versaroc cement bonded particle board (produced by the Mayapple Corporation) contains 71% Portland cement, 19% wood particles, 9% water and 1% bonding agent.

CBPB has a typical density of 1250 – 1400 kg/m3. The relatively high density reduces the board flexibility and requires the pre-drilling of holes for fixture. This type of board possesses relatively high expansion and shrinkage properties when exposed to moisture due to its high wood content. A high pH (11) makes it extremely durable and resistant to wood-boring insects and fungi. CBPB also has a high level of fire-resistance (Moslemi and Hamel, 1989; Moslemi et al., 1889; Saunders and Davidson, 2014).

4.4 Wood Strand Cement Board (WSCB)

Wood Strand Cement Board (Fig. 4) is the least common type of cement board. WSCB possesses fire, moisture, fungal, impact and insect resistance. As a medium density board (1100kg/m^3) it has a remarkably high strength. Great scrutiny has been placed upon WSCB, with extensive scientific analysis performed to assess its properties (Saunders and Davidson, 2014; van Elten, 2013).

4.5 Others

Glass cement board, Plastic cement board, Feather cement board etc. are other cement bonded boards. Furthermore wood-plastic cement board is a famous board like wood-wool cement board. Textile-reinforced concrete (TRC) composite is made of a cement-based matrix (paste, or fine-grained concrete, also known as mortar) reinforced with textile fabric. The properties of TRC composite are dependent on the properties of the textiles, including material types and geometries, the cement-based matrix properties and the bonds developed between them (Peled, 2016).

Fig. 4(a): Fibre cement board (FCB) is made of cement, water, fillers and fibres. The fibres may be synthetic (right) or natural

Fig. 4(b): Wood wool cement board (WWCB) is made of cement, water, salt and wood wool fibres. Typical densities of 350-570 kg/m^3

Fig. 4(c): Cement bonded particle board (CBPB) is made of cement, wood particles and water.

Fig. 4(d): Wood strand cement board (WSCB) is made of cement, water, salt and wood wool fibres. Density of 1100 kg/m^3

.

Fig. 4. Different types of cement bonded boards (Saunders and Davidson, 2014; van Elten, 2013).

5 RAW MATERIALS USED IN CEMETN BONDED BOARD

A raw materials are materials or substances used in the primary production or manufacturing of a particular product. 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.

5.1 Cement

Cement is a powdery substance mixed with water to form mortar or mixed with sand, gravel, and water to make concrete. In other word, a powdery substance made with calcined lime and clay act as a binder.

5.1.1 Classification of cement

There are mainly two types of cement:

a) ***Non-hydraulic cement:*** Will not set in wet conditions or underwater. It contains mostly calcium hydroxide (>95%).

b) ***Hydraulic cements:*** Set and become adhesive due to a chemical reaction between the dry ingredients and water e.g., portland cement. This is the mixture of silicates and oxides.

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.

Table 2. Types of portland cement according to ASTM standard

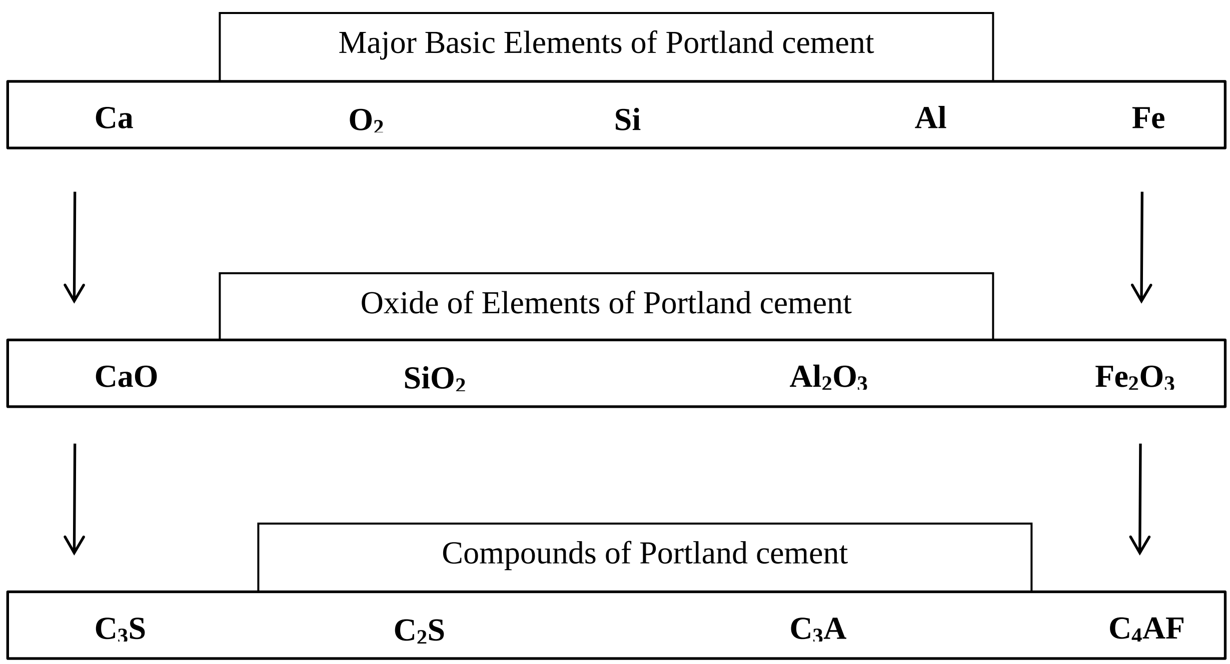
	Classification	Characteristics	Applications
Type I	General purpose/Ordinary Portland Cement	Fairly high C_3S content for good early strength development	General construction (most buildings, bridges, pavements, precast units, etc)
Type II	Moderate sulfate resistance	Low C_3A content (<8%)	Structures exposed to soil or water containing sulfate ions
Type III	High early strength/Rapid or Extra-rapid Setting	Ground more finely, may ave slightly more C_3S	Rapid construction, cold weather concreting
Type IV	Low heat of hydration (slow reacting)/Low heat/Pozolana/Slag	Low content of C_3S (<50%) and C_3A	Massive structures such as dams. Now rare.
Type V	High sulfate resistance/Super-sulphate resisting	Very low C_3A content (<5%)	Structures exposed to high levels of sulfate ions
White	White color	No C_4AF, low MgO	Decorative (otherwise has properties similar to Type I)

5.1.2 Chemical composition of OPC

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding. Table 3 shows the approximate oxide composition limits of ordinary portland cement.

Table 3. Approximate oxide composition limits of ordinary portland cement

Oxide	**Per cent content**
CaO	60-67
SiO_2	17-25
Al_2O_3	3.0-8.0
Fe_2O_3	5.0-6.0
MgO	0.1-4.0
Alkalies (K_2O, Na_2O)	0.4-1.3
SO_3	1.3-3.0



C_3S (Tricalcium Silicate), C_2S (Dicalcium Silicate), C3A (Tricalcium Aluminate), C_4AF (Tetracalcium Aluminoferrite)

Major compounds of ordinary portland cement can be found in Table 4.

Table 4. Major compounds of OPC

Chemical Name	Chemical Formula	Oxide Formula	Cement Notation	Mineral Name	Percentage
Tricalcium Silicate	Ca_3SiO_5	$3CaO.SiO_2$	C_3S	Alite	62.1
Dicalcium Silicate	Ca_2SiO_4	$2CaO.SiO_2$	C_2S	Belite	16.4
Tricalcium Aluminate	$Ca_3Al_2O_6$	$3CaO.Al_2O_3$	C_3A	Aluminate	6.2
Tetracalcium Aluminoferrite	Ca_2AlFeO_5	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	Ferrite	8.6
Calcium sulfate dihydrate	$CaSO_4.2H_2O$	$CaO.SO_3.2H_2O$	$C\ H_2$	Gypsum	-

5.1.3 Function of OPC

Ordinary portland cement mix with water makes mortar, other reinforcement materials additives and chemicals are used to make cement bonded board. Portland cement when mix with water it hydration reaction starts and thus cement gets hardening.

Hydration reactions and products as well as their function can be found in Table 5 and Table 6.

Table 5. Hydration reactions and products

Cement Notation		Water		Products		
C_3S (Ca_3SiO_5)	+	H_2O	$\longrightarrow$	C-S-H Gel	+	$Ca(OH)_2$
C_2S (Ca_2SiO_4)	+	H_2O	$\longrightarrow$	C-S-H Gel	+	$Ca(OH)_2$
C_3A ($Ca_3Al_2O_6$)	+	H_2O	$\longrightarrow$	Tetracalcium aluminate hydrate		

C_4AF (Ca_2AlFeO_5)	+	H_2O ⟶	Calcium aluminoferrite hydrate
C H_2 ($CaSO_4.2H_2O$)	+	H_2O ⟶	Calcium monosulfoaluminate

Table 6. Function of ordinary portland cement

Products	**Amount (%)**	**Functions**
C-S-H Gel	50	Responsible for most of the engineering properties
Ca(OH)2	15	Slightly to strength & impermeability. However, leach out, increase porosity, chemical attack & consume other chemicals
C-S-A-F	15-25	Do not contribute much to the engineering properties of concrete
Others	20	Link between the solid hydration products and the outside environment

5.2 Water

Water is an available material and used in cement bonded board production. Portland cement is widely used for cement bonded board production. When water is mixed with cement it starts chemical reaction known as hydration resulting hardening process and makes board hardy. Water is used to mix the reinforcement materials as well as additives with cement, and Portland cement set and become adhesive due to a chemical reaction between the dry ingredients and water.

5.3 Reinforcing Material

Reinforcement material is a material used in composite that provides strength properties of composites. The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties. All of the different fibers used in composites have different properties and so affect the properties of the composite in different ways. In cement bonded board lignocellulosic fibers such as wood, agricultural materials etc or others non-lignocellulosic fiber materials such as, plastic, glass, feather etc. are used as a reinforcement materials.

5.3.1 Lignocellulosic material

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).

5.3.1.1 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).

5.3.1.2 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 (Youngquist, 1999).

5.3.2 Other than Lignocellulosic Materials

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).

5.4 Source of Reinforcing Raw Materials

a) Wheat straw**:** It is one of the major cereals that have been used in several countries. After harvesting the crop, a large quantity of straw, estimated to be more than the crop itself, is available as waste. The present worldwide generation is about 709 million tons per annum. It has been reported that wheat straw has a more complicated microstructure than that of wood. In addition it has more variability in terms of cell type and size. In comparison to wood it has shorter fibres and thinner cell walls. Wheat straw and wood materials contains almost equivalent amount of cellulose (_45%). However, the hemicellulose content is higher (28%) and the lignin content is lower (18%) when comparing with wood samples (23% and 27%, respectively) (Halvarsson et al., 2004). Wheat straw has desirable geometric and mechanical characteristics for making cement-bonded particleboards, but its inhibitory effect on cement hydration is a constraint. The higher hemicellulose content may be responsible for greater inhibitory effect on cement hydration. Nevertheless, using accelerated processing techniques based on carbonation reactions cement–wheat straw boards were successfully made. These boards meet the minimum standard mechanical, durability and physical requirements (Soroushian et al., 2004).

b) Rice straw**:** Rice is also an important cereal, used in all parts of the world. For harvesting the rice crop the top portion of the rice stem along with 3–5 leaves is cut and the remainder is left in the field. It is estimated that globally about 673 million tons of rice straw is available annually. In India, about 72% of the rice straw is used by the farmers for fodder, fuel and thatch roofs; 26% is sold for different purposes and remaining is burnt (Ganapathy, 1997). Cement bonded rice straw boards using two cement: rice-straw ratios of 60:40 and 50:50 (Fernandez and Taja-on, 1997). The densities of the boards were 1670 kg/m3 and 1430 kg/m3, respectively. Flexural strength of the board varied between 1.5 and 7.0 MPa depending upon the use of chemical admixtures. The water absorption of these boards was rather high. It varied between 24% and 42%.

c) Coir: Coconut is a tropical plant grown mostly in the sea shore areas. The external part of the coconut fruit becomes fibrous with maturity. The fibres from the outer skin can be obtained by soaking in water or by mechanical means. These fibres are called coir fibre and are short in length. Their main application is in making ropes. Their stiffness is very sensitive to moisture and they have relatively low cellulose content (Agopyan, 1988; Balaguru and Shah, 1992). The high lignin and low cellulose contents make coir fibre a resilient, strong and highly durable material. Its low density is the result of cavities formed by moisture loss from the cells during drying (Reis, 2006). The use of coir fibres for making cement-bonded boards revealed that the optimum fibre content was 15% by weight of the mix, fibre length 30 mm and moulding pressure

3 MPa (Aggarwal, 1992). The optimum coir fibre was 20% by weight of cement, fibre length less than 2 mm (Khedari et al., 2001). The resultant composite has thermal conductivity of 0.254 W/m K, comp. strength of about 2.4 MPa (10 days) and bulk density 958 kg/m3. The coir fibres need pre-treatment of boiling and washing (Asasutjarit et al., 2007). The optimum fibre length was 10–60 mm and cement: coir: water ratio was 2:1:2. The physical and mechanical properties of the coir cement boards were comparable to that of the commercially available boards. The conclusions of these studies are not consistent particularly with respect to the optimum fibre length. More research work is required in this direction.

d) Hazelnut shell: Turkey is the largest producer of hazelnuts followed by Italy and Spain. A large quantity of hazel nut shells is available as waste. (Demirbas and Aslan, 1998) attempted to use it for making cementitious composite. They studied the effects of ground hazelnut shell, spruce and beech woods, and tea waste upon the mechanical properties of cement. They found that an increase in these lignocellulosics content in the mix leads to lower compressive and flexural strengths for the cementitious composite. Mixes of ground hazelnut with cement showed the smallest relative decrease whereas the effect of tea waste was very severe. No clear reason was reported for this behavior. However, it could be due to the presence of tannin in the tea waste. They concluded that ground hazelnut shell and beech wood could be used as an additive material in making cementitious composites.

e) Oil palm residues: Life time of palm trees 25–30 years. Thereafter about 500–600 kg of trunks and fronds from each tree is generated as waste. In addition, fibre, shells and empty bunches from the trees are also available in substantial quantity. Presently, major part of the oil palm shells and fibres are used for power generation, while remains are either sold as fuel or used for road construction. The empty bunches are burnt to obtain potash rich ash used as fertilizer in farming. Malaysia is the largest producer of palm oil, where the plantation area is further increasing (Nordin et al., 2004). Several attempts have been made to use the wastes from oil palm trees in making cement-bonded materials. Cement-bonded boards using oil palm fibre/cementitious materials ratio of 1:2.5 and a target density of 1300 kg/m3 (Hermawan et al., 2001). They concluded that with 10–20% of cement replacement materials like fly ash, rice husk ash and rubber latex and the chemical admixtures, boards can be produced that meet the strength and dimensional stability requirements. (Basri et al., 1999) investigated the use of oil palm shells

(OPS) as coarse aggregate for making lightweight concrete. Their results indicated that OPS concrete had a 28-day air dry density of 1801–1856 kg/m3 in comparison to 2301 kg/m3 for the control concrete. They reported that the strength was within the normal range for structural light weight concrete. Oil palm frond retards cement setting (Hermawan et al., 2001). However, the addition of $MgCl_2$ accelerated cement setting and also improved the strength properties of the composite. Recently, (Mannan et al., 2006) reported the results of a study conducted to improve performance of OPS concrete by applying various types of pre-treatment methods. They found that a coating of 20% PVA to OPS was the most suitable pre-treatment. The PVA solution forms a thin layer on the OPS, which resists the water ingress into the OPS and also facilitates good bonding between OPS and cement paste.

f) Cork granules: Waste cork granules are very lightweight granular waste obtained from cork bottle stoppers producing industries. The cork granules have a cellular structure. A research study was conducted to use these cork granules for making lightweight concrete that has versatile applications (Karade, 2003). The results indicated that the addition of cork considerably reduces the density of the composite and enhances failure strain. These properties of the composite are attributed to the cellular structure of cork (Karade, et al., 2001). Furthermore, a good bonding between cork and cement paste was observed. Composites with a wide range of density (400–1500 kg/m3), compressive strength (1–26 MPa) and flexural strength (<1.5 MPa) can be made. The composites have good energy absorption efficiency and low thermal conductivity (Karade et al., 2001). Accordingly they can be used in various civil engineering structures. In comparison to many other woody materials, cork has good compatibility with cement (Karade et al., 2006). The results indicated that the large granules (2–3 mm) are more compatible with cement, but yield products with lower compressive strength. The cork dust, i.e. the small size granules (<0.2 mm), yields moderate strength, but affect hydration in the initial stages. It is possible that these properties could be improved further by the application of pre-treatments to improve the compatibility of cork.

g) Bark: Bark of various wood species from saw mill is available as waste. However, it is not considered suitable for making cement bonded composites, because it contains a large amount of extractives and has great retarding effect on cement setting. An investigation to use Japanese cedar bark material in making cementitious composites (Eusebio et al., 1996). They found that the bark inhibits the hydration of cement. However, the addition of $MgCl_2$ and Na_2SiO_3 improved the hydration behavior of the composite with a negligible change in compressive strength. The composite properties like bending strength, stiffness and internal bond were improved by addition of $MgCl_2$ for boards produced using the conventional pressing method, while Na_2SiO_3 was effective in the steam injection pressing (SIP) method only. Yet, the properties were lower than those required to meet the standard specifications. The main reason for this is that bark hardly provides any reinforcing effect. Therefore further research is required to make bark–cement composites incorporating some fibres.

h) Bagasse: The residual obtained after extraction of juice from the sugarcane is called bagasse. It is composed of about 50% fibres, 30% pith including moisture and about 20% soluble solids (anon., 2002). However, the quality of fibres depends upon various parameters like sugarcane quality, maturity, and milling efficiency of the machine (Balaguru and Shah, 1992). Bagasse is available in most of the countries. It is composed of pith and thick walled fibres which have a length of 1–4 mm. The present industrial applications of bagasse fibres are in the production of particleboards and fibre boards. In India, it is also used as a fuel for steam generation and as a raw material for the production of pulp and paper (Aggarwal, 1995). Some research work has also been carried out to convert bagasse into value-added industrial products like liquid fuels, feed stocks, enzymes and activated carbon (Reis, 2006). To use bagasse in making cement-bonded composites materials retained on 2 mm mesh should be used (Eusebio, 2004). It has also been suggested that a bagasse–cement ratio of 1:2 should be selected to make boards of 1.00 g/cm3 density. While bagasse content 12–16% by mass, casting pressure 2–3 MPa and demoulding time more than 6 hour (Aggarwal, 1995). It has been found that if bagasse is heat treated at 200 C, the bagasse–cement mix has cement like hydration behavior (Bilba et al., 2003). However, the thermal treatment of bagasse fibres before mixing is a costly process for a product like building board. Therefore, other pre-treatment processes or addition of suitable chemical admixtures should be explored.

i) Arhar stalks: Arhar is an annual crop sown during early part of the rainy season (June/July) in India and other south Asian countries like Pakistan, Bangladesh and Sri Lanka. It is harvested in winter (November–December) and the main product is arhar pulse obtained by processing the arhar crop. After removal of the arhar seeds, the stems and branches of its plant (arhar stalks) remain as waste. These stalks have length up to 3 m and diameter up to 75 mm. Presently, the thinner sections of the arhar stalks are used as a fuel and the thicker sections are used for making hut roofs. These dry stalks are cheap, strong and durable. To explore the possibility using arhar stalks for making cement-bonded composites an investigation was undertaken (anon., 2005). It was found that the water extractives of arhar stalks are slightly acidic (pH value 6.5) and that they retard the cement setting. The increase in setting time was 25–130% for extractive content 0.5–2% by weight of cement and reduction in 28-days compressive strength was 13–20% at 1–2% extractive content. However, the magnitude of these effects was reduced by prior cold water extraction and/or by use of an accelerator. A dose of 2% calcium chloride, by weight of cement, could offset the effect of 1% concentration of arhar extractive. The cement-bonded composites were prepared by varying the flakes content from 0% to 32%, by weight, in the flakes–cement mix using a moulding pressure of 3 MPa and demoulding time up to 10 h. Composite boards with bending strength more than 9.0 MPa and internal bond strength greater than 0.6 MPa can be made, which meets the minimum requirements specified by International Standard, ISO: 8335–1987 for the cement-bonded boards (Aggarwal, 2008).

j) Waste Timber: Traditionally, timber has been an essential construction material. However, with the invention of reinforced concrete, use of timber has been reduced. From the demolition of old buildings and structures, a large quantity of wood as wastes is available. Most of the timbers used in construction are being treated with chemical preservatives during their service life to protect them from biological deterioration. Chromated copper arsenate (CCA) is known to be the most common wood preservative composed of the oxides of chromium, copper, and arsenic. Other preservatives like acid copper chromate, ammoniacal copper arsenate, and ammionacal copper zinc arsenate also contain high concentrations of heavy metals (Solo-Gabriele and Townsend, 1999). This creates difficulty in disposal as they are resistant to biodegradation and if incinerated the ash may contain unacceptable concentration of heavy metals.

k) Waste MDF: Medium density fibreboard (MDF) is a popular lignocellulosic material used in building construction and in furniture industry. It is made by compressing under heat a mix of wood or other lignocellulosic fibres and a synthetic resin generally urea–formaldehyde. Presently, the world production rate is about 22 million m3 and growing day by day. In comparison to other building materials like bricks, concrete or wood, it has shorter life-span. A large quantity of after service MDF is available as waste, which further increases with the addition of cutting wastes obtained during manufacturing and fabrication. Like other lignocellulosic wastes, it is also either burnt or landfilled. (Qi et al., 2006) used wastes of medium density fibreboard (MDF) for making wood–cement composites.

l) Furniture industry waste: During manufacturing of furniture items, waste is generated in various forms such as pieces of solid wood and fibre boards saw dust and cane strands. The use of rattan (cane) furniture waste for the manufacture of cement-bonded particleboard (Olorunnisola and Adefisan, 2002). They applied hot-water extraction as a pre-treatment of the chopped strands and added $CaCl_2$ as an accelerator.

Properties of some cement-bonded composites incorporating lignocellulosic wastes are represented in Table 7.

Table 7. Properties of some cement-bonded composites incorporating lignocellulosic wastes

Organic aggregate	**Source**	**Composite density, kg/m3**	**Composite strength, MPa**	**Flexural strength, MPa**	**Reference**
Pine wood	Construction waste	800–1220	1.10–6.64	0.57–1.65	(Wolfe and Gjinolli, 1999)
Conifer (cedar, cypress and pine)	Construction waste	920–1250	5.00–8.00	4.00–7.00	(Kasai et al., 1998)
Hazelnut shell	Agro-waste	-	26.50–43.70	4.40–7.00	(Demirbas and Aslan, 1998)
Coconut fruit shell	Agro-waste	1090–1340	-	1.56–3.80	(Almeida et al., 2002)
Oil palm shells	Oil palm industry	1801–1856	15.00–20.00	-	(Basri et al., 1999)
Oil palm frond	Oil palm industry	1200	-	5.00–23.00	(Hermawan et al., 2001)
Cork granules	Cork industry	400–1500	1.00–26.00	0.50–4.00	(Karade, 2003)
Bark of Japanese cedar	Forestry waste	1200	10.00–22.00	2.00–8.00	(Eusebio, et al., 1996)
Rattan (palmae)	Cane furniture	1050–1200	0.50–1.60	-	(Olorunnisola and Adefisan , 2002)

m) Others: Other than lignocellulosic there are some cement bonded board like; plastic cement board, glass cement board, wood-plastic cement board, feather cement board (Table 8). Chicken is a large source for feather. Beverage bottle is the largest source for plastics. Other recycled materials like, plastic, glass etc. are also used.

Table 8. Physical and mechanical properties of some non-lignocellulosic fiber (Shao et al., 2001).

Type	**Diameter (mm)**	**Length (mm)**	**Density (g/cc)**	**Strength (MPa)**	**Modulus (GPa)**
Polyethylene terephthalate (PET) fiber	30	6	1.1	50– 100	1.2-2
Alkaliresistant (AR) glass fiber	14 (strand)	12	2.6	3600	70
Polyolefin (PO) fiber	60	18	0.91	275	2.8
Polyvinyl alcohol (PVA) fiber	14	6	1.3	1400	36

5.5 Additives

There is a growing desire to improve the properties and use of non-wood plant materials as supplements to wood materials for wood cement-bonded boards (WCBs). Different types of additives are used in cement bonded board to improve the properties as well as getting desire product such as alkali-resistant glass fiber, normal glass fiber, mineral wool, and non-wood plant materials such as retted flax straw and wheat straw particles (Wei et al., 2001).

5.6 Other Chemicals

There are some common problem in cement bonded board such as, long curing time, heavy weight (high density) etc. The drawbacks of Portland cement in combination with wood are already addressed by different authors (Fan et al., 2012; Hachmi et al., 1990; Pereira et al., 2006; Simatupang and Geimer, 1990) and are often solved by using accelerators. However, for the low density wood cement board fulfilling only pre-treatment by e.g. water treatments, small additions of chlorides (depending on the required class) or long time storage can be applied to reduce the inhibitory effect. For the high density board fulfilling the two more methods can be applied, i.e. by applying higher amount of cement (reducing the inhibitory effect) and using of accelerators (no restriction on chloride content) to further reduce the inhibitory effect.

6 MANUFACTURING PROCESS OF CEMENT BONDED BOARD

Cement boards are made of mixtures of cement, water and either reinforcing fibres or particles. The resulting mix is formed into sheets or continuous mats, stacked (and/or pressed), dried and trimmed to size. We already known that there are different types of cement bonded board. Cement bonded fiber boards, cement bonded particle boards, Wood wool cement boards, wood strand cement boards and their different types, but their manufacturing process more or less same. When we talk about cement bonded board manufacturing process, all the reinforcement materials can be taken as a raw material such as, in case of cement bonded particle board, the raw material is particles, in case of cement bonded fiber board, fiber is the raw material, I case of wood wool cement board, wood and wool are the raw materials, in case of wood strand cement board, we need wood strand as a raw materials and so on. According to desire products type one or two processes can be excluded or included. Based on the information I have found so far about manufacturing process of cement bonded board, I made a general flow diagram of manufacturing process of cement bonded boards.

The general flow diagram of cement bonded board can be found in Fig. 5. More details about manufacturing process of cement bonded board are available in (Fei et al., 2002).

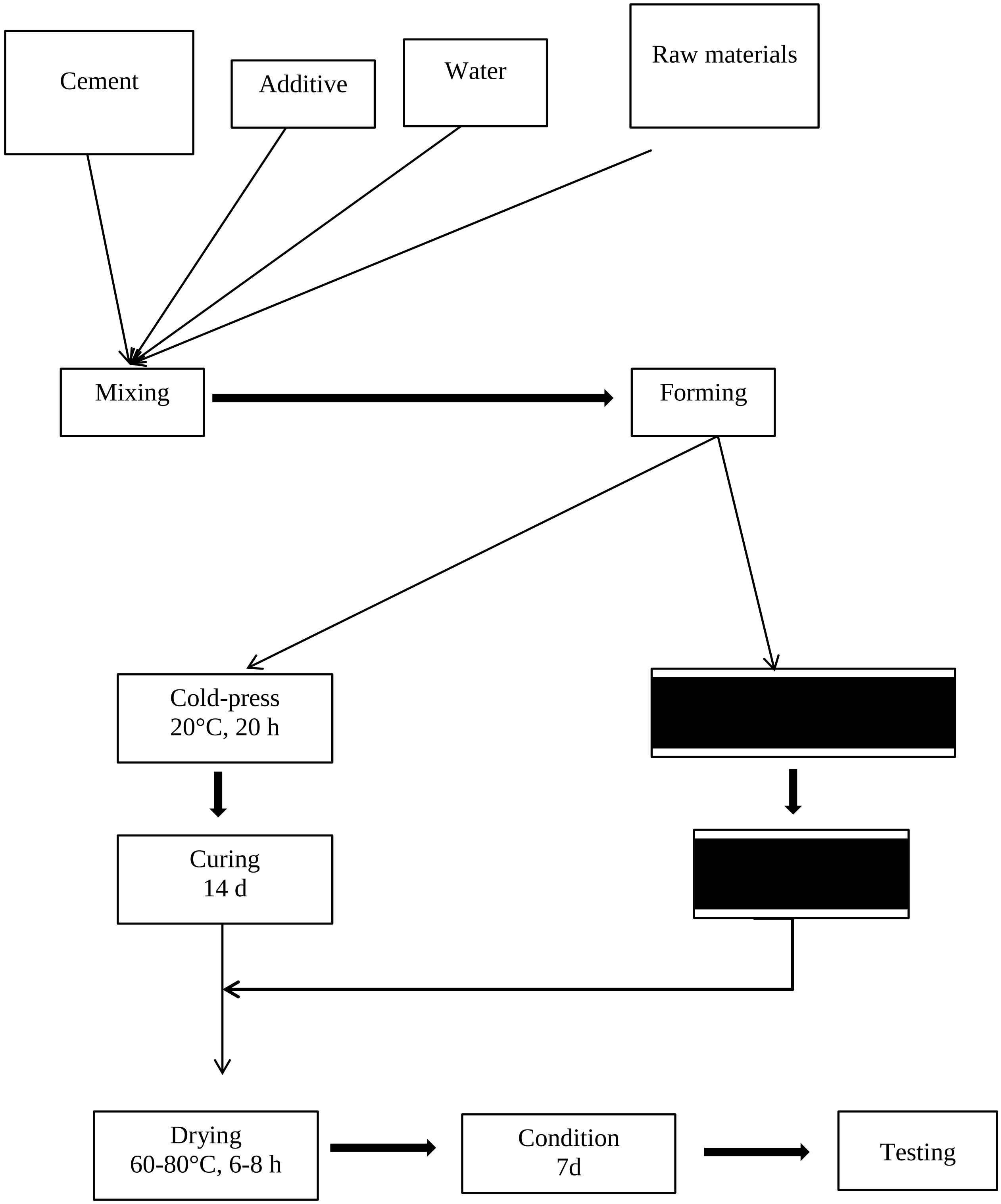


Fig. 5. General flow diagram for the manufacture of cement-bonded boards (Fei, et al., 2002)

Individual manufacturing process of important distinct categories of cement bonded boards is discussed below:

6.1 Manufacturing Process of Wood-wool Cement Board (WWCB)

An overall manufacturing process of Wood-wool Cement Board (WWCB) can be found in Evans (2002). WWCB was first developed in Europe in the 1920s (Moslemi and Hamel, 1989) and it is currently manufactured in many countries around the world. WWCB is made from debarked softwood or hardwood logs that have been stored for varying periods of time to reduce the starch and sugar content of the wood. After storage, logs are cross-cut into billets and these are shredded on a cutting machine to produce wood-wool. Typical wood-wool strands used in the manufacture of WWCB are approximately 3 mm wide and 0.5 mm thick with lengths up to 40–50 cm coinciding with the lengths of the billets processed by the shredding machines. Coarser wood-wool is often used in the manufacture of very thick boards.

When hardwood species with a high extractive content are used, the wood-wool may be soaked in cold water overnight to remove any soluble low molecular-weight sugars and heartwood extractives that might interfere with cement hydration reactions. Wood-wool may also be treated with inorganic compounds such as calcium chloride, again to reduce the inhibitory effects of soluble wood components on the setting of cement. Wood-wool is air-dried and mixed with cement using a cement-to-wood ratio of 2-to-1 to 1-to-1 (w/w). The mixed material is conveyed to a mat former and a pre-determined weight of cement coated wood strands is deposited on a forming board. In LDCs, mat-forming may be done by hand (Pablo, 1989). The mats are then stacked and pressed in a hydraulic press at room temperature in batches of 8–12. The pressure used for pressing varies depending on the degree of densification required in the final board, but can be as low as 80 kPa for low-density insulation boards. The stack is clamped under pressure for 24 hours to allow for initial cement cure to occur. Boards are then declamped and post-cured for 2–3 weeks before trimming and finishing (Moslemi et al., 1889; van Elten, 2013;)

6.2 Manufacturing Process of Cement Bonded Particle Board (CBPB)

Evans (2002) described 5.1 Manufacturing Process of Cement Bonded Particle Board (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. 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}. While the stack of cauls 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 cauls 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; Tachi et al., 1889; Saunders and Davidson, 2014).

6.3 Manufacturing Process of Cement Bonded Fiber Board (CBFB)

Wood-fibre reinforced cement composites are manufactured from wood-fibre (7–8.5%), sand (60%), cement (30%), and aluminium trihydrate (3–4%) (w/w). The wood-fibre, which is usually obtained from softwood chemical (kraft) pulp, acts as a reinforcing agent in the boards, a role previously played by asbestos fibres in an older generation of building materials. The manufacture of wood-fibre reinforced cement composites involves washing the sand and reducing it to a fine powder using a ball mill. Bales of kraft pulp are added to a vat containing water and agitated to redisperse the fibres. Fibres are then refined or beaten twice in conical refiners to increase their ability to interact with sand and cement (Coutts and Ridikas, 1982). The cement, sand, fibres and additives are combined in the proportions outlined above and diluted to form a slurry with a solids content of 10%. The slurry is fed into a tub containing three screen cylinders which pick up the slurry mix and deposit it on a felt-like belt moving at 80 m min^{-1}. The belt is then turned so that the slurry is on top and while this is occurring the fibre-cement mat is trimmed at its edges by water jets and partially dewatered using vacuum suction boxes. The mat passes under a large drum that winds layers of fibre-cement around itself. A cut-off knife or wire releases the mat from the drum and it is then deposited onto a conveyor belt. After leaving the conveyor belt the fibre-cement mat is cross-cut; mats are cured by autoclaving for 6–8 h at temperatures and pressures of approximately 200°C and 900 kPa, respectively. In the absence of autoclaving, curing of boards takes approximately 28 h. From the autoclave, boards are transferred to a finishing plant where their edges are trimmed and their surfaces sanded (van Elten, 2013; Saunders and Davidson, 2014; Evans, 2002).

6.4 Manufacturing Process of Wood Strand Cement Board (WSCB)

A composite composed of wood strands and a cement-based matrix named Cement Strand Slab (CSS), was developed and the influence of manufacturing conditions on its strength properties was examined (Miyatake et al., 1998).

A wood strand cement board, manufactured from a mixture consisting essentially of wood strands not of woody grasses, a major portion of all said wood strands having a length of at least 250 mm, a cement binder and water which mixture is cured to form a board with a practically entirely closed surface. Wherein said wood strands have a width of at least 2 mm, a width of maximally 12 mm, and a thickness of at least 0.15 mm and maximally 1 mm and wherein the weight ratio of water to wood strands is maximally 1.20:1, and wherein said wood strands are not embedded in a matrix of cement and wherein edges of the strands are pointed at angles of less than 120° (van Elten, 2013).

The basic mixture needed to produce WSCB is much the same as WWCB, namely a mixture of wood fibres, cement and water in a 1:2:1 ratio (by dry weight). The use of additives during the production of WSCB is also common. Wood strand cement board differs from wood wool cement board mainly by density, which results from alterations to the manufacturing process and the wood fibres. Significantly, the wood fibres in WSCB are thinner and wider than those used in WWCB production (Tachi et al., 1889; van Elten, 2013; Saunders and Davidson, 2014).

6.5 Others

There are different other types of cement bonded boards such as cement bonded plastic board, wood-plastic cement board, feather cement board, glass cement board. More or less manufacturing process of these types of boards is same even as like other cement bonded board. Plastic, glass, feather etc. are used as reinforcing materials and cement act as a binder. There are polyethylene terephthalate (PET) fiber, alkali resistant (AR) glass fiber, polyolefin (PO) fiber, and polyvinyl alcohol (PVA) fiber (Shao et al., 2001).

7 BONDING BETWEEN CEMENT AND REINFORCING MATERIALS

7.1 Compatibility of Cement with Reinforcing Materials

Wood, plastics can work as reinforcing agents and as a filler to lower the density of concrete. Also, wood-cement composites have several advantages when compared to solid wood: they are generally more resistant to bio-deterioration, to moisture and to fire. (Andrade and Caldeira, 2010). Though recycling of plastics in plastic-cement composites does not pose any questions regarding chemical compatibility manufacture wood-cement composites with recycled wood, physio-mechanical properties of composites must be assessed. (Andrade et al., 2010) A key issue when examining the suitability of wood species for the manufacture of wood–cement composites is the effect that the wood has on the hydration (setting) of cement. When wood and water are added to cement, hydration reactions occur and heat is evolved. During the initial stages of hydration, di- and tri-calcium silicates are converted to bermorite gel ($Ca_3Si_2O_7.3H_2O$) and calcium hydroxide ($Ca(OH)_2$). The latter increases the pH of the wood–cement mixture to approximately 12.5, which facilitates dissolution of wood constituents, particularly low molecular-weight carbohydrates and heartwood extractives. These compounds can interfere with cement hydration (Sandermann and Kohler, 1964) and setting, resulting in wood–cement composites of inferior strength. Such deleterious interactions between wood and cement can be more pronounced with certain wood species, for example western larch (*Larix occidentalis*), because they possess greater quantities of cement-inhibiting compounds that are easily leached from the wood in the alkaline environment of cement (Zhengtian and Moslemi, 1985). Alternatively, certain species, for example *Acacia mangium*, can contain soluble compounds which, although present in the wood in small quantities, may have strong inhibitory effects (Tachi et al., 1989). Wood species that greatly inhibit cement hydration are classified as incompatible with cement and therefore unsuitable for the manufacture of wood–cement composites.

The influence of fabric-textile structures on bonding with cement matrices and their consequential influence on the control of the mechanical performance of cement composites was studied by Bentur et al. (1997), Peled et al. (1997, 1998 a,b, 1999) and Peled and Bentur (2000, 2003).

7.2 Determining Compatibility

Different methods, such as measuring the hydration characteristics (Alberto et al., 2000; Brandstetr et al., 2001; Hachmi and Moslemi 1990; Hachmi et al., 1990; Karade et al., 2003; Sandermann and Kohler 1964; Sandermann et al., 1960; Sauvat et al., 1999; Schubert and Wienhaus, 1984; Weatherwax and Tarkow, 1964; Wei et al., 2000a; Wei et al., 2000b), measuring the mechanical properties of the cured wood cement mixtures (Lee and Hong 1986), the visual evaluation of the microstructural properties (Ahn and Moslemi, 1980; Davies et al., 1981; Wei et al., 2004; Wei et al., 2003), and measuring the electrical conductivity during setting (Backe et al., 2001; Govin et al., 2005; Simatupang et al., 1991), exist so as to determine compatibility of wood and cement. The peak of the hydration temperature, as well as the time duration until this temperature is reached, give information on the suitability of a specific species to be bonded with cement. This level of suitability is expressed by the "inhibitory index". All these methods are based on the height and the delay of the maximum hydration temperature. Good suitability is normally expected when a hydration temperature of more than 60°C is reached, whereas a hydration temperature of less than 50°C signifies a completely unsuitable species (Sandermann and Kohler, 1964). For comparison when neat cement is used, a maximum hydration temperature of more than 80°C can be observed (Sandermann et al., 1960). The relationship of hydration temperature and mechanical strength was proven by Sandermann and Kohler (1964). However, Miller and Moslemi (1991) do not recommend using hydration characteristics as estimates for actual strength, except for very general valuation. It appears that the compatibility tests that use relatively fine particles are suitable for comparing the compatibility of different wood species in the laboratory, but under real manufacturing conditions, where different particle sizes are used, this comparison may not be valid. Wood that is found to be incompatible using fine particles might be compatible with coarse particles. Analysis of fine particles, however, can provide valuable information on the maximum possible effect of wood-extractives, as finer particles expose more surface area to the cement paste, and thus more extractives can enter into the solution (Karade et al., 2003). A more sophisticated method, because of the unpredictable influences of the wood particles and the long curing times, is to determine compatibility by measuring the mechanical properties of cured samples (Morrissey et al., 1985; Sandermann and Brendel, 1956; Sandermann et al., 1960; Seddig and Simatupang, 1988).

7.3 Improvement of Compatibility and General Properties

Because of their inhibiting contents some "aggressive" wood species, such as Larix decidua, are able to completely stop hydration of cement (Sandermann and Kohler, 1964) which can be seen in a degradation of the physical properties (Jorge et al., 2004). On this account, strong inhibiting species need some special treatment to make them suitable for the production of cement bonded wood based materials (Moslemi et al., 1983). By removing soluble compounds, the compatibility can be improved. There are different methods to accomplish this aim, conventional hot or cold water extraction and soaking, respectively (Eusebio et al., 2000b;; Okino et al., 2005; Schwarz and Simatupang, 1984; Sutigno, 2000), long-time (Moslemi and Lim, 1984) storing of the raw material (Cabangon et al., 2002), many chemical extraction methods (Alberto et al., 2000; Kavvouras1987; Moslemi et al., 1983;), and even treatment by fungi (Thygesen et al., 2005), whereby the latter can cause more or less severe damage that will manifest itself in declined mechanical properties of the CBC. 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. Also quite common is the use of Na_2SiO_3, which can either be applied as described above or for extraction of the raw material. However, improvement of the mechanical properties as well as mitigation of thickness swelling by the use of Na_2SiO_3 is weak compared to water- or NaOH-extraction (Kavvouras, 1987).

In addition, Simatupang et al., (1987) mention the possibility of applying different kinds of blocking layers around wood particles. Naturally, this method could have the disadvantage of hindering the direct contact between wood particles and matrix, which could result in weakened mechanical properties. 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 (Geimer et al., 1994; Geimer et al., 1993; Hermawan et al., 2002a, b; Hermawan et al., 2000; Hermawan et al., 2001a; 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 super plasticizers. 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). The total water amount of the bonding components also represents an important factor in the hydration of cement. This total amount is made up of the moisture content of the solid wood and the water from the cement slurry. If too dry wood is used, water, which is necessary for the cement hydration, will be withdrawn from the slurry. This will lead to a decrease in final strength (Dewitz et al., 1984). Contrarily, if too much water is added, negative effects on the strength properties can also be expected (Miyatake et al., 2000).

7.4 Accelerators for Improvement of Compatibility and General Properties

There are some common problem in cement bonded board such as, long curing time, heavy weight (high density), high water absorption etc. Further the drawbacks of Portland cement in combination with wood are already addressed by different authors (Fan et al., 2012; Hachmi et al., 1990; Pereira et al., 2006; Simatupang and Geimer, 1990) and are often solved by using accelerators such as water glass, sodium hydroxide, portlandite, and chlorides.

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. 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 (Geimer et al. 1994; Geimer et al., 1993; Hermawan et al. 2002b; Hermawan et al., 2000; Qi and Cooper 2007; Qi et al., 2006; Simatupang and Bröker 1998; Simatupang and Habighorst, 1993a, b, c; Simatupang et al., 1995; Simatupang and Neubauer, 1993; Simatupang et al., 1991; Soroushian et al., 2004;

Soroushian et al., 2003; Wagh et al., 1994; Wagh et al., 1997; Young et al., 1974). 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 (Badejo 1988; Bejó et al., 2005; Hermawan et al., 2002b; Hofstrand et al., 1984; Kavvouras 1987; Moslemi et al., 1983; Papadopoulos et al., 2006). The use of CO_2 is a promising method to accelerate the hydration process (Geimer et al., 1992; Hermawan et al., 2002a; Simatupang and Habighorst, 1992). 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).

8 COMPOSITION OF CEMENT BONDED BOARD

Cement bonded boards are mainly cement bonded particles boards and cement bonded fiber boards. 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 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 to 40 mm thickness making it ideally suitable for high load bearing applications. 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 to 20 mm thickness. Many manufacturers use additives like mica, aluminium stearate 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%. 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.

Cement bonded particle board is produced from particles which we can get from either wood or non woody materials. Generally Cement bonded particle boards (CBPB) are manufactured from Wood-particles (20.70%), Portland cement (66.70%), Additives (1.9%), Water (10.70%), and composition can be found (Faria et al., 2013). A graphical representation of composition of Cement Bonded Particle Board can be found in Fig. 6.

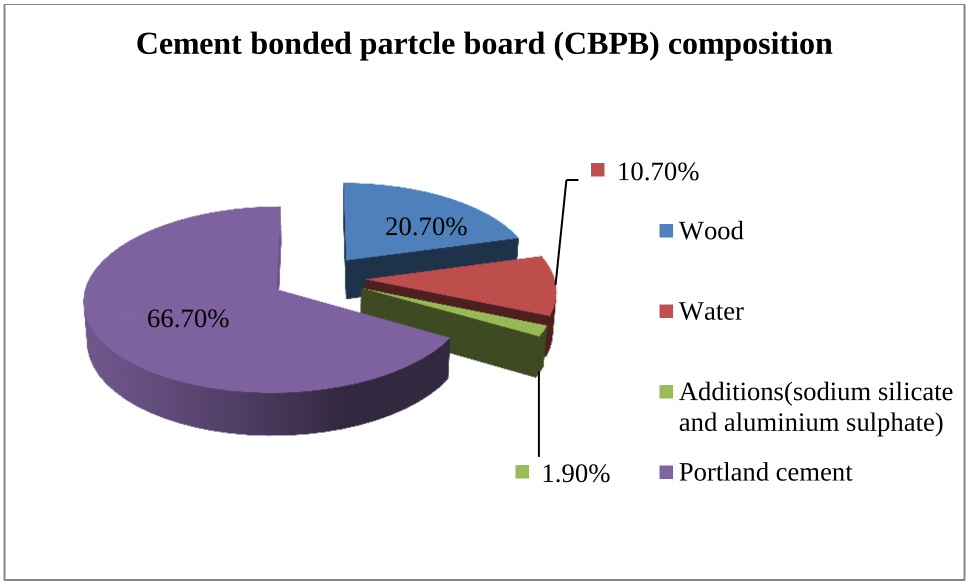


Fig. 6. Composition of CBPB (percentage of constituents by weight) (Faria et al., 2013)

Wood fiber agricultural residue fiber reinforced cement bonded board are manufactured from fiber (7-8.5%), sand (60%), cement (30%), and aluminium tri-hydrate (3-4%). The wood fiber is usually obtained from softwood chemical pulp. They act as a reinforcing agent in the boards, a role previously played by asbestos fibers in an older generation of building materials. The proportions outlined above are combining the cement, sand, fibers and additives and diluted to form slurry with a solids content of 10% (Shakri, 2008). Graphical representation of composition of Cement Bonded Fiber Board is available in Fig. 7.

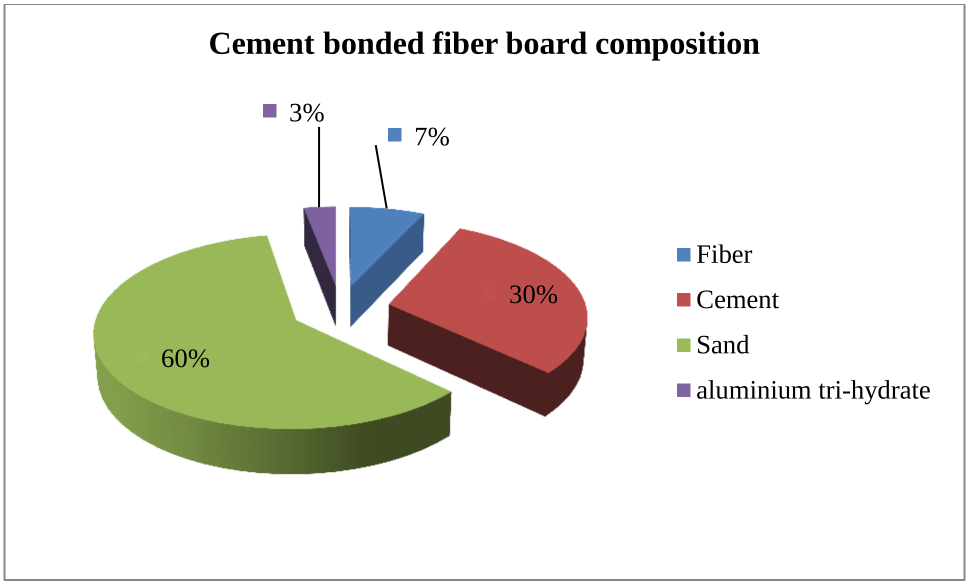


Fig. 7. Composition of CBPB (percentage of constituents by weight) (Shakri, 2008)

9 PROPERTIES OF CEMENT BONDED BORD

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). Typical particle sizes for WPC are 10 to 80 mesh (Clemons, 2002) and the smaller particle size yields better performance ((Takatani et al., 2000). 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; Lu et al., 2000; Caulfield et al., 1998; Hwang 1997; Stark and Rowlands, 2003; 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). Comparisons between wood-plastic composites and conventional wood composites are studied and indicate that wood fiber-plastic composite panels are inferior to conventional wood-based panels in bending modulus of elasticity and bending modulus of rupture. However, the composite panels performed well in thickness swell and moisture absorption (Falk et al., 1999).

Besides wood, many agri-based particle and fiber types have been investigated, including bamboo, wheat, kenaf, cornstalk, jute etc (Chow et al., 1999; Caulfield et al. 1998; Rowell, 1996; Young et al., 1996). English et al., (1997) studied the comparison between wood and mineral fillers in composites and indicated that wood filler can reduce the specific gravity of composites, which is an advantage in packing and transportation application. The interaction and adhesion between the fiber and matrix has a significant effect in determining the mechanical and physical behavior of fiber composites (Sanadi et al., 2000; Stark 1999; Caulfield et al., 1998; Oksman and

Clemons, 1998; Clemons 1995). Fiber fracture (or lack of it), polymer ductility, and fiber polymer bonding all play a role in impact performance (Clemons, 1995). Research about decay resistance of WPC due to weather, moisture, insects or fungi are studied in several papers, including laboratory and field tests, (Lopez et al., 2005; Verhey et al., 2003; Clemons and Ibach 2002; Pendleton et al., 2002; Verhey et al., 2001; Falk et al., 2000a; Hwang and Hsiung 2000; Falk et al., 2000b; Chow et al., 1999; Morris and Cooper, 1998) in which good qualities of wood-plastic composites in dimension stability, weather resistance, moisture absorption and fungi resistance are proven. Wang and Morrell (2005) indicate that moisture absorption tend to increase with the number of wet/dry cycle. Besides, ultraviolet exposure can lead to photo degradation, resulting in a change in appearance and/or mechanical properties (Stark et al., 2002; Falk et al., 2000b). One of the disadvantages of cellulose-based fibers is their propensity to absorb water and swell. This inevitably leads to undesirable dimensional instability of the composite and its fiber-mat preform. A measure of the hygroexpansion behavior of the fibers could serve to rank the suitability of different kinds of cellulosic fibers with regard to dimensionally stable composites. A method has been developed to determine the hygroexpansion coefficient of wood fibers. Since fiber mats manufactured with conventional techniques generally have a thickness gradient of fiber orientation, fiber mats and composites will curl if the moisture content varies (Neagu et al., 2005). The toughness of filled polymers can be improved in several ways: 1) increase the matrix toughness; 2) optimize the interface (or interphase) between the filler and the matrix through the use of coupling agents, comptibiliser, and sizes; 3) optimize the filler-related properties such as filler content, particle size, and dispersion; 4) aspect ratio and orientation distributions also play a role in toughness of composites containing more fiberous materials (Oksman and Clemons, 1998). Fastener properties are also studied. Screw withdrawal, nail withdrawal, and nail head pull-through capacity are relatively unaffected by wood flour content. However, wood flour content affected lateral nail resistance. The use of pilot holes (predrilling) was found to have little effect on fastener capacity. Moreover, the screw withdrawal capacity of the tested wood flour-thermoplastic composite panels was found to be equal to or greater than that of conventional wood panel products (Falk et al., 2001). Parsons and Bender (2004) studied the dowel connection in wood-plastic composites hollow section.

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. 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. House construction utilizing these type of technology is taking place in a number of countries where such panels are vertically, bolted together for quick assembly. In addition to home construction, cement bonded particle board is used in nonresidential construction as cladding and as facing. 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. Table 9 provides a comparison of some of the important strength properties for cement bonded board as compared with some other panel products. 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).

Table 9. Comparison of some mechanical properties of cement bonded particle board with a number of other panel products (Moslemi, 1989).

Properties	**Gypsum-bonded Particle board**	**Cement bonded Particle board**	**Gypsum fiber board**	**Gypsum plaster board**	**Resin bonded particle board**
MOR (MPa)	6-10	9-16	5-8	5-8	12-24
MOE (MPa)	2-4	3-6	2-4	2-4	2-4
IB (MPa)	0.3-0.6	0.4-0.7	0.3-0.5	0.2-0.3	0.5-1.0
Tensile Strength (MPa)	3-4	4-5	2-3	2-3	7-10

Cement bonded boards can be nailed, sawed, and otherwise machined with wood working tools. At higher densities, however, the materials must be screws and nails. The board density, however, can be manipulated without difficulty, which offers a considerable range of properties. Other important properties such as heat and sound insulation, fire resistance, nail and screw withdrawal resistance, and finishing qualities with paints and other coating are important practical consideration (Andersen, et al., 2009). Properties of different types of cement bonded boards can be found in Table 10.

Table 10. Properties of different types of cement bonded boards (Saunders and Davidson, 2014)

Cement Board Type	**Properties**
Fibre cement board (FCB)	Durable and impact resistant.
	Resistant to fire, moisture and decay.
	Can be printed on.
	Relatively easy to handle due to low weight.
Wood wool cement board (WWCB)	Low bending strength and elasticity.
	Resistant to fire, moisture, fungus, vermin and freeze-thaw.
	Easy to handle and transport due to very low weight.
Cement bonded particle board (CBPB)	High expansion/shrinkage properties when exposed to moisture.
	Durable and impact resistant.
	Resistant to fire, wood-boring insects and fungi.
Wood strand cement board (WSCB)	High bending strength and elasticity.
	Durable and impact resistant.
	Resistant to fire, moisture, fungus, vermin and freeze-thaw.
	Relatively easy to handle due to low weight.

The bonding of fabric reinforcement is much more complicated, due to the function of the yarns transverse to the load direction and the complex geometries of the individual reinforcing yarns that make up the fabric. These yarns provide anchorage, as well as the mono- or multifilament nature of the yarn. The bonding mechanism and the microstructure in the vicinity of the yarn/fabric, that is, at the yarn (fabric)–matrix interface can be rather different, depending on: the form of the yarn (mono- or multifilament), the fabric and its yarn geometry, the composition of the yarn (fibre) material and yarn coating and filling (Shao et al., 2001).

10 APPLICATIONS OF CEMENT BONDED BOARD

Wood Wool Cement Board (WWCB) is a versatile building material made from wood wool (excelsior) and cement. The world wide acceptance of WWCB proves its versatility in applications and its durability in any climatic condition for the following feature of WWCB (source: https://www.eltomation.com/eng/wood-cement-boards/wood-wool-cement-board):

As Fire resistance, Wet and dry rot resistance, Freeze-thaw resistance, Termite and vermin resistance, Thermal insulation, providing energy savings, Acoustic performance (sound absorption), Acceptance of a wide range of finishes

Traditionally wood wool cement boards have been applied in Europe as a base for gypsum plaster or cement stucco and for permanent shuttering and insulation of concrete. Later in some countries (Scandinavia, Holland) non-stuccoed, spray painted acoustic ceiling boards have proven to be very successful and are now increasingly being used in several other countries as well. In the sixties so called Sandwich or Composite Boards were introduced, offering higher insulation values. These boards consist of one or two outer layers of WWCB with a core of a rigid foam of polystyrene or polyurethane. To further improve the fire resistance also composite panels with mineral wool are produced. For an increased span of roofing boards, wooden laths (Holland) or poles (Sweden) embedded in the boards allow for a free span of up to 1, respectively 2 meters and with steel channels at the edges (UK) up to 4 meters. In case of a special shape of the board and channels according to our UK Patent 1,094,689 a free span of up to 6 meters is obtained. In developing countries various systems were developed for mass production of low income houses. For the description of these systems I refer to my earlier lectures for the Food and Agriculture Organization of the United Nations (FAO) and the World Association for Element-Building and Prefabrication (WAEP) (van Elten, 1999; Evans, 2002; Saunders and Davidson, 2014).

As a Basements and Floor Units, Outside Walls (Permanent Shuttering, Insulation of Concrete, Large size Wall Elements), Roofing, Renovation, Ceilings, Acoustic Absorption, Sound Barriers (Table. 11).

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 (Evans, 2002; Elten and Bert, 2006; van Elten, 2006; Saunders and Davidson, 2014).

Successful application of cement bonded particle board (van Elten, 2006):

As a Flooring with tongue and grooved boards; large size prefabricated elements for permanent shuttering of concrete walls and floors, the production of complete prefabricated houses.

Approximate distribution for the following applications:

As a Raised Floors (15%), Office containers, influenced by new governmental fire and moisture regulations (20%), Supply to prefabricated house manufacturers (15%), Various supplies to the industry (25%), amongst others for kitchens, bathrooms and furniture, Facades (5%), Various, including high fire resistant class boards (20%) (Fig. 8)

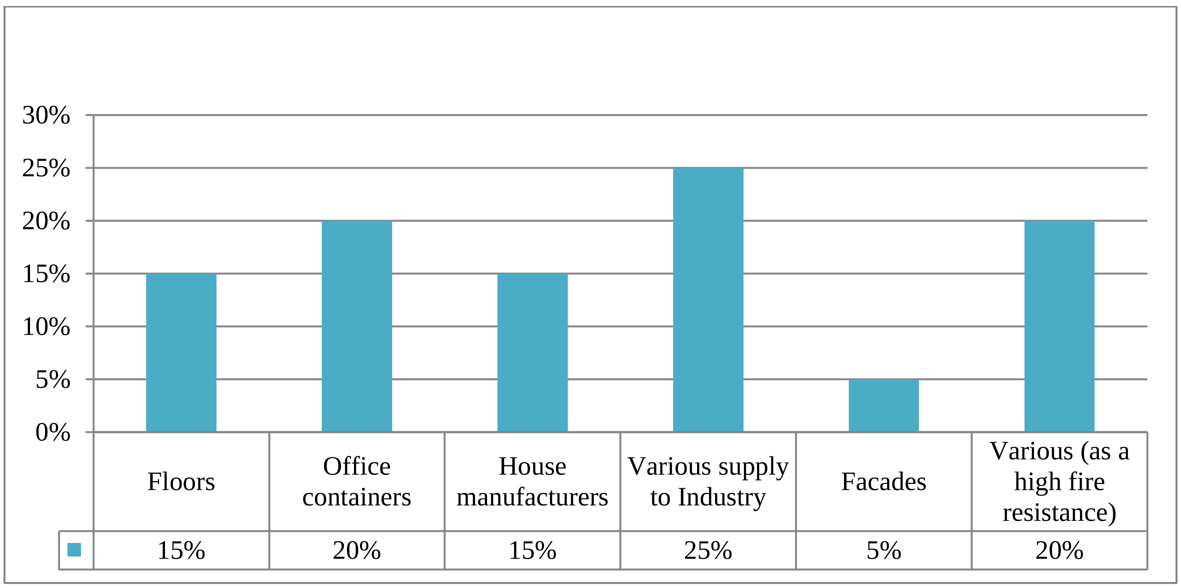


Fig. 8. Use pattern of cement bonded board (van Elten, 2006; Evans, 2002; Elten and Bert, 2006; Saunders and Davidson, 2014).

Table 11. Showing application of different types of cement bonded boards (Elten , 2013; Saunders and Davidson, 2014).

Cement Board Type	Applications
Fibre cement board (FCB)	Roofing, shingles and shales.
	Exterior and partition walls.
	Flooring, underlay and tile-backing.
	Prefabricated houses.
	Façades, weatherboard and cladding.
Wood wool cement board (WWCB)	Flooring, underlay and tile-backing.
	Roofing, shingles and shales.
	Permanent shuttering.
	Prefabricated houses.
	Acoustic and thermal insulation.
	Fire resistant construction.
	Ceilings and architraves.
Cement bonded particle board (CBPB)	Prefabricated houses.
	Roofing, shingles and shales.
	Permanent shuttering.
	Exterior and partition walls.
	Soffits, ceilings and architraves.
	Production of fire and moisture resistant furniture.
	Façades, weatherboard and cladding.
Wood strand cement board (WSCB)	Flooring, underlay and tile-backing.
	Roofing, shingles and shales.
	Permanent shuttering.
	Prefabricated houses.
	Exterior and partition walls.
	Acoustic and thermal insulation.
	Fire resistant construction.
	Facades, weatherboard and cladding.

11 ADVANTAGES AND DISADVANTAGES OF CEMENT BONDED BOARD

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. 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)

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

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)

12 STATUS AND PROSPECT OF CEMENT BONDED BOARD IN BANGLADESH

Though cement bonded board has been used since 1900s and more than 90 cement bonded board producer companies all over the world, there is no commercial production of cement bonded board in Bangladesh.

The first particle board industry established in 1962 in our country named star particle board mills ltd., which is a jute based particle board industry. It was also first particle board industry in Asia. In Bangladesh the journey of wood based particle board industry started in 2006. After 2006 the particle board demand is increasing day by day and it is highly promising sector in Bangladesh. Particleboard applications include furniture, cabinets, floor underlayment, sub flooring in manufactured housing, door cores, and many other non-structural industrial applications.

Though particle board has many indoor uses, particle board is not appropriate for outdoor use due to the fact it can expand and become discolored when exposed to moisture, very vulnerable for termite attack. Another problem of particle board includes limited durability. The most important concern is particle board resins are typically formaldehyde-based. These resins, because of their formaldehyde emissions it is not environmental friendly, can causes serious health risk.

Cement bonded particle board can overcome all of these problems. Already discussed that very high density, long curing time makes cement bonded board more expensive than others, also need a very high investment initial cost to introduce cement bonded board in Bangladesh.

Forest resource is very low compare to what needed in our country, but the demand of wood and non-wood forest products is increasing rapidly for over population in Bangladesh. Cement bonded board can be good alternative in this case and which is environmental friendly. We expect a good prospect of cement bonded board in Bangladesh which can help us to save our existing forest resources. But need commercial production of cement bonded board in our country.

Several researches have been conducted to produce cement bonded board from different raw materials under Forestry and Wood Technology discipline, Khulna University, Khulna, Bangladesh. One of the projects is ongoing “Commercializing of cement bonded particle board from agricultural residues”. So we can say that cement bonded board has a good future in Bangladesh

13 CONCLUSION

The forest resources are decreasing in at alarming rate day by day in our country due to the high demand of wood based products. Particle board or plywood or related industries are meeting our demand, but nowadays we are very much concerned about our environment, particle board or plywood or related industries use synthetic resin like formaldehyde which causes several problem in environment and susceptible for health risk of living beings. Furthermore raw materials of cement bonded board mostly comes from different waste materials such as agricultural residues, residues from furniture industries and other wood and non-wood fiber based industries, these raw materials have no appropriate use, sometimes used as a fuel where low calorific value and most of the case they are stored and dumped as a waste materials in our environment. Cement bonded boards have a good prospect in our country which have greater utilization value over other types of board, as well as it can save our environment. In our country it can be used as construction materials such as roofing, flooring, wall and other paneling. It can be used as an alternative of tiles. Though need high investment cost but it can give a better product with better environment. Need more research and an appropriate plan to make cement bonded board commercial.

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