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EFFECTS OF CHEMICAL ADDITIVES ON THE PHYSICAL AND MECHANICAL PROPERTIES OF KENAF (*Hibiscus cannabinus* L.) CORE CEMENT-BONDED PARTICLEBOARD

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DECLARATION

I, Md. Abdullah-Al-Mamun, Student ID. MS-130510, declare that the thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Khulna University or other institutions.

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Dedicated To

My Beloved Parents

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Md. Abdullah-Al-Mamun

ABSTRACT

The study was conducted to reduce the density of the cement-bonded board and to evaluate the improvement of the properties of cement bonded board made from Kenaf core (*Hibiscus cannabinus* L.) by chemical additives treatment. In this study two types of particles size fine (F) and course (C) were taken and four types of chemical treatments boards untreated (UT), treated with $MaCl_2$ (TM), Treated with $NaHCO_3$ (TN) and treated with combination of $MaCl_2$ & $NaHCO_3$ (TMN) were produced. The density of the UTF, UTC, TMF, TMC, TNF, TNC, TMNF and TMNC was 0.836, 0.818, 0.842, 0.834, 0.843, 0.835, 0.869 and 0.847 g/cm^3 respectively. In case of water absorption and thickness swelling it has been found that, the boards treated with additives show lower value than the untreated board. On the other hand the board treated with additives show higher mechanical strength (MOR & MOE) than the untreated one. Besides these, boards made from course particles show higher mechanical properties however in case of water absorption board of finer particle show better result. The board treated with combination of $MaCl_2$ & $NaHCO_3$ shows greater mechanical properties than the board treated with $MaCl_2$ and $NaHCO_3$ separately. The addition of chemical additives in the production of cement-bonded board increases the both physical and mechanical properties of the Kenaf core cement bonded board. Besides these, the properties were also influenced by the particles size of raw materials. Hence it can be concluded that the Kenaf core can be an alternative source of raw material for manufacturing of low density cement-bonded board.

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ABBREVIATIONS

Anon	Anonymous
ASTM	American Society for Testing and Materials
BFRI	Bangladesh Forest Research Institute
CBP	Cement-Bonded Particleboard
UTF	Untreated board with Fine particles
UTC	Untreated board with Course particles
TMF	Magnesium chloride Treated board with Fine particles
TMC	Magnesium chloride Treated board with Course particles
TNF	Sodium hydrogen carbonate Treated board with Fine particles
TNC	Sodium hydrogen carbonate Treated board with Course particles
TMNF	Magnesium chloride + Sodium hydrogen carbonate Treated board with Fine particles
TMNC	Magnesium chloride + Sodium hydrogen carbonate Treated board with Course particles
cm^3	Cubic Centimeter
df	Degrees of Freedom
FAO	Food and Agricultural Organization
IB	Internal Bond Strength
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Megapascal
OD	Oven-dry dimension
OPC	Ordinary Portland Cement
SD	Standard Deviation
N	Newton
TS	Thickness Swelling
WA	Water Absorption

CHAPTER ONE

INTRODUCTION

1.1 General introduction

A wood particle bonded together with an inorganic material such as ordinary Portland cement (OPC) is referred to as cement-bonded particleboard (CBP). Particleboard manufactured using mineral cement as the binding agent is gradually gaining importance in many countries of the world. Cement bonded particle boards (CBP) are already used thoroughly in Europe, United States, Russia and S.E. Asia, mainly for roofs, floors and walls. They possess countless advantages compared to panels produced with organic resins which are high durability, good dimensional stability, acoustic and thermal insulation properties and low production cost. Present world is very concerned about environmental pollution. 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 lingo-cellulosic materials in which most are based on natural renewable resources.

In recent years, several research groups have been evaluating the suitability of different lignocellulosic materials for the manufacture of CBP including cypress (Okino *et al.* 2005), rubberwood (Okino *et al.* 2004), eucalyptus (Okino *et al.* 2004; Evans *et al.* 2000; Del Menezzi and Souza, 2000; Latorraca, 2000), pines (Cabagon *et al.* 2002; Teixeira and Pereira, 1987), acacia (Eusebio *et al.* 2002; Teixeira and Guimarães, 1989), agricultural residues (Almeida *et al.* 2002) and fiber (Del Menezzi *etal.* 2001).

There are obstacles to the utilization of these materials for CBP. The main problems are the inhibitory effect caused by wood on the cure of cement and the high density of the final product. Wood component, mainly extractives and polysaccharides, affects reactions between wood and cement resulting in boards of low quality. (Jorge *et al.* 2004) argued that the nature of the extractives also has influence on this inhibitory effect. To solve inhibition problems, it is common to add inorganic chemicals, known as accelerators, to accelerate the cure of cement or use pretreatments such as aqueous extraction to remove inhibitory substances from wood. Chemical additives usually improve the properties of CBP (Jorge *et al.* 2004).

This research aims to reduce the density by using low density Kenaf core (0.1-0.2 gm/cm^3) as raw materials and to improve the quality of cement-bonded particleboard by treated with chemical additives.

1.2 Objectives of the study

1. To develop low density Kenaf core cement-bonded particleboard.
2. To enhance the performance of Kenaf core cement-bonded particleboard by addition of chemical additives.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Brief History about cement-bonded particle board

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 though it can be used for different types of furniture or decorative purposes. Considering this 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).

In Indonesia the first mineral-bonded board made of saw dust was established in 1952 in Pontiana, and in 1956 another mineral-bonded board type was established in Palembang. This board used saw dust and shavings as raw materials. In 1970s there were 6 mineral bonded board mills in Indonesia and four of them used excelsior or wood-wool and the rest used wood flakes in the mix. However the development of this board industry was not last long because it was not supported by settlement industry to result in limited production and inadequate sales. This experience will be good consideration for future development of mineral-bonded board industry in Indonesia (Sutigno, 1991).

Cement bonded particle board (CBP) established itself in Switzerland and central Europe in the mid-1970s and has been imported in UK since the late 1970s. The number of plants worldwide is over 40, with one in the UK (Desch and Dinwoodie, 1996). Currently, there are over 38 plants in operation throughout the world (Moslemi, 1989). An extensive development of CBP industry has taken place throughout the world during 1980-90 when 12 plants were established in Soviet Russia, five in Japan, two each in Germany and Turkey, and one each in Malaysia and Thailand. Stillinger and wentworth (1977) pointed out that in tropical and subtropical countries, the problem of building low cost dwelling houses that would withstand extreme climatic conditions and last long can be solved by using high density wood-cement board.

The industrial application of pressure to manufacture wood-cement panels did not occur until the about mid-1930s.

Table 2.1 Industrial production of inorganic-bonded wood composites (Kossatz *et al.*, 1983).

Year	Product
1900	Magnesite-bonded boards
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 fibreboards
1972	Magnesite-bonded wood composite panels
1982	Gypsum particleboard
1990	Wood wool cement board
2000	Wood strand cement board

2.2 Inorganic-bonded board

Inorganic binders fall into three main categories: gypsum, magnesia cement and Portland cement. Gypsum and magnesia cement are sensitive to moisture, and their use is generally restricted to interior applications. Composites bonded with Portland cement are more durable than those bonded with gypsum or magnesia cement and are used in both interior and exterior applications. Inorganic-bonded composites are made by blending proportionate amounts of lignocellulosic fiber with inorganic materials in the presence of water and allowing the inorganic material to cure or "set up" to make a rigid composite. All inorganic-bonded composites are very resistant to deterioration, particularly by insects, vermin and fiber.

2.3 Board performance

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 are not suitable for load bearing elements are often used with framing materials like wood and steel section (Eusebio, 2003).

Table 2:2 General properties of low density cement wood fabricated using excelsior-type particles (Eusebio, 2003).

Property	**From**	**To**
Bending strength	1.7MPa	5.5MPa
Modulus of elasticity	621 MPa	1241MPa
Tensile strength	0.69 MPa	4.1MPa
Compression strength	0.69 MPa	5.5MPa

Cement bonded properties offer a verity 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 grooves can be cut into flat panel surfaces. The use of special adhesives enables the manufacturer 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 verity of finishes. Cement bonded particle board offer properties that, in some respects, are unique to this kind of material. Table 2.2 provides a comparison of some of the important strength properties for cement bonded particleboard as compared with some of the other panel products. These boards generally have a lower modulus of rupture than resin bonded particle-board but are superior in modulus of elasticity. Table 2.3 also provides comparison with gypsum-bonded particleboard and fiber board as well as gypsum plasterboard (Stillinger and Wentworth, 1977).

Table 2.3: 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	3-8	12-24
MOE(Gpa)	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 in board plane (Mpa)	3-4	4-5	2-3	2-3	7-10

A major advantage of cement bonded boards is the ability to withstand outdoor exposure. Fire resistance is particularly important consideration for cement bonded-boards, especially considering the need for a replacement for asbestos boards. High fire resistance can lead to a new market opportunities and expanded production in many countries. Some cement bonded particleboard manufactures content that the composite is practically fireproof. Biological deterioration due to insects and fungi is minimal with these boards. The highly alkaline nature of the material coupled with the cement-encased structural of wood particles makes such attacks very difficult. Under microscopic examination, early cement-bonded particleboard samples in use for some 25 years in a building in Switzerland showed no structural change in wood tissues. (Parameswaran and Broker, 1979) the samples were free of insects and fungal damage. 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, nail and screw withdrawal resistance, and finishing qualities with paints and other coating are important practical consideration

2.4 Natural Pozzolans

Pozzolans are defined as siliceous or silicious and aluminious materials that can react chemically with calcium hydroxide (lime) at normal temperatures in the presence of water to form cement compounds. Some common Pozzolanic materials include vocalic ash, fly ash, rice husk ash, and condensed silica fume. All these materials can react with lime at normal temperatures to make natural water resistant cement. Pozzolans increase the strength of the cement but slow the cure time and decrease the alkalinity of Portland cement.

2.5 Carbon dioxide treatment

In the manufacture of cement bonded lingo-cellulosic composite, the cement hydration process normally requires from 8 to 24 hours to develop sufficient board strength and cohesiveness to permit the release of consolidation pressure. By exposing the cement to carbon dioxide, the initial hardening stage can be reduced to less than 5 minutes. This phenomenon results from the chemical reaction of carbon dioxide with calcium hydroxide to from calcium carbonate and water. Research has demonstrated that composites treated with carbon dioxide can be twice as stiff and strong as untreated composites. Carbon dioxide- treated composites do not experience efflorescence (migration of calcium hydroxide to surface of material), so the appearance of the surface of the final product is not change over time (Anon, 1987).

Shortening the pressing time of cement bonded particle board, while at the same time enhancing its physical and mechanical properties, was done by the addition of isocyanate resin (Eusabio *et al.*, 1993; Eusabio *et al.*, 1994) and the incorporation of sodium bicarbonate ($NaHCO_3$) with the application of steam injection pressing (Eusabio *et al.*, 1995; Nagadomi *et al.*, 1996).

Hot pressing method was not welcome move to manufactures, as it will entail additional investments for the equipment. One of the recent developments that would improve the manufacturing method is by storing the logs or billets prior to processing. It revealed that cold water extraction to remove the inhibitory effect on cement is not necessary. This would eliminate the use of too much water for soaking and saves on drying of the excelsior (Cabangon *et al.*, 2000).

One of the major technological problems in this product involves the incompatibility of some wood species with Portland cement. This is due to large amount of hydrolysable hemi-cellulose present in woods. Portland cement is a hydraulic binder and is manufactured by sintering a mixture containing mainly CaO, SiO_2, Al_2O_3, and

Fe_2O_3. The alkaline produced by cement dissolves the extractives and hemi-cellulose, which, in turn, react as retardant to cement. Consequently, further problem appears, i.e. long setting and curing period needed for cement to fully hydrate before attaining adequate strength.

The question of weight is another problem particularly when cement-bonded particle board is compared with other wood panels. The density of cement bonded particle board is considerably higher than the resin-bonded particleboard. Opportunities for weight reduction remain and need to be pursued.

Some other problems are encountered in manufacturing of lignocellulosic cement composites, such as: the different durability of lignocellulosics in combinations with portland cement, and consequently that of the composites; and occurrence of efflorescence (Moslemi and Lim, 1984; Moslemi and Lim, 1985; Yasuda *et al.*, 1989).

In the conventional manufacture of Portland cement bonded particle boards, the setting time is reduced by the addition of chemical additives or admixtures to the wood cement water systems and incremental temperature during setting and curing period. Such additives as monoethanolamine and diethanolamine, calcium cloride, have been used to enhance cement setting. Other additives such as ferric chloride, ferric sulfate, magnesium chloride, calcium hydroxide, aluminum chloride, calcium formiate, and calcium acetate have been reported as lowering the inhibitory effects of wood on setting of Portland cement (Weather and Tarkow, 1964).

2.8 Additives Treatment

Recently additives treatment has done in many countries to improve the mechanical properties of cement-bonded particleboard by reducing the inhibitory index and increase the compatibility. The hydration temperatures of bamboo or oil palm frond powder and cement mixtures with or without additives were examined. The inhibitory index (I-value) and compatibility factor ($C_{A\text{-value}}$) for each mixture were determined and the compatibility of each additive with the hydration of cement was evaluated; low values of hydration temperature peaks (T_{max}) were observed for both the bamboo-cement and oil palm-cement mixtures without additives. The presence of inhibitors in the cement mixtures resuted in lower T_{max} compared to neat cement. Magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) as additives improved the compatibility of bamboo-cement, whereas $MgCl_2$ improved the oil palm-cement compatibility. Larger amount additives, in general, resulted in higher T_{max} values.

The cement-bonded particleboard from bamboo and cement-bonded fiberboards from oil palm frond were successfully manufactured by using the conventional cold pressing method with the above additives. The mechanical and the dimensional properties of the boards were tested in accordance with the Japan Industrial Standard, JIS A 5908. In order to obtain adequate mechanical strengths, 10-15% of $MgCl_2$ or $CaCl_2$ and 7.5-10% of $MgCl_2$ were needed for bamboo-cement particleboard and oil palm-cement fiberboard respectively (Ma *et al.* 2000).

To assess the compatibility of bamboo with cement, the maximum hydration temperature and the time required to reach that maximum were measured. The additives were sodium hydrogen carbonate ($NaHCo_3$), sodium carbonate (Na_2CO_3), sodium silicate (Na_2SiO_3), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$). Based on the hydration temperature, magnesium chloride and calcium chloride improved the compatibility of bamboo powder and cement higher peak temperatures and hardness values were observed when $CaCl_2$ and $MgCl_2$ were used as additives (Ma *et al.* 2000). The initial setting of cement is accelerated by the addition of sodium carbonates. Although there were not much difference between the addition of $NaHCO_3$ and Na_2CO_3, there were some improvements in the hydration rates and the board properties with increases in additive contents. The compatibility factor (C_A) id calculated by using the following equation:

$C_A = (A_{WC}/A_{NC})\ 100$

Where A_{WC} is the area under the hydration rate curve for sample cement-water mixture, and A_{NC} is the area under the hydration rate curve for neat cement-water mixture.

In recent years few methods of rapid curing systems for cement- bonded particle boards by using additives together with stream-injection pressing or hot platen pressing for the initial setting of cement, followed by autoclaving or heating treatment for the subsequent curing, were also developed (Yasuda *et al.*, 1986; Nagadomi *et al.*, 1996; Ma *et al.*, 2000).

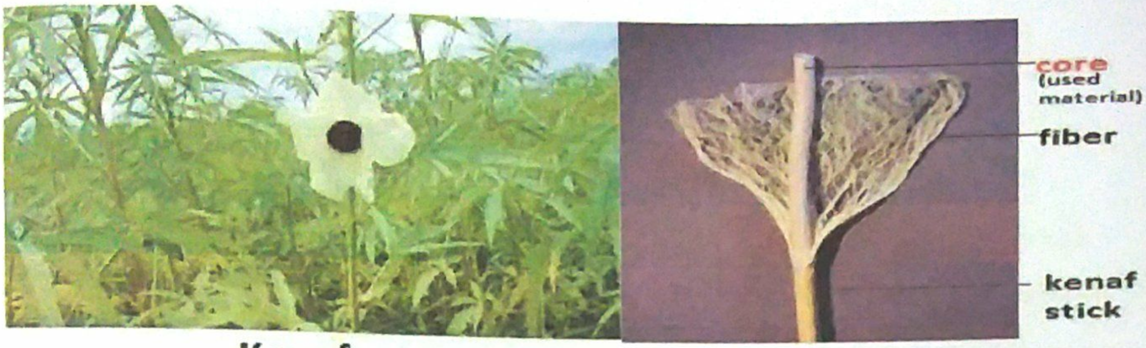
In the production of composite panels from the annual crop and rice husk materials, some problems still exist in seasonality, storage, scattering sources, and bond ability (Rowell *et al.*, 1997) with any annual crop, harvesting must be done at a certain time. Storage of huge quantities of these bulky materials away from microbial degradation and bad weather conditions is of difficulty. Besides, collection of these materials from scattering farm sites and transportation to a central spot is also concern (Rowell, 1995).

2.7 General information of Kenaf (*Hibiscus cannabinus*)

Kenaf (*Hibiscus cannabinus*), is a plant in the Malvaceae family. It is in the genus *Hibiscus* and is probably native to southern Asia, though its exact natural origin is unknown. The name also applies to the fibre obtained from this plant. Kenaf is one of the allied fibres of jute and shows similar characteristics. Common name of Kenaf is English: kenaf (Persian origin), Java jute, French: chanvre de Bombay, German: Ambari, Dekkanhanf, Portuguese: cânhamo rosella, juta-de-java, India (Bengal): *mesta* India (Marathi): *Ambaadi*India (Tamil): *pulicha keerai'palungi.* It is an annual or biennial herbaceous plant (rarely a short-lived perennial) growing to 1.5-3.5 m tall with a woody base. The stems are 1–2 cm diameter, often but not always branched. The leaves are 10–15 cm long, variable in shape, with leaves near the base of the stems being deeply lobed with 3-7 lobes, while leaves near the top of the stem are shallowly lobed or unlobed lanceolate. The flowers are 8–15 cm diameter, white, yellow, or purple; when white or yellow, the centre is still dark purple. The fruit is a capsule 2 cm diameter, containing several seeds.

Almost 60% of the kenaf production in Far East countries (2010/11) is in India (140 thousand tones), with China to contribute with 32 % to the total production, Pakistan with 5% and Indonesia with 1%.

The fibres in kenaf are found in the bast (bark) and core (wood). The bast constitutes 40% of the plant. These fibres are long (2 – 6 mm) and slender. The cell wall is thick (6.3 µm). The core is about 60% of the plant and has thick (ø 38 µm) but short (0.5 mm) and thin walled (3 µm) fibres.[4] Since the paper pulp is produced from the whole stem, the fibre distribution is bimodal. The pulp quality is similar to hardwood. Seeds contain radium, thorium, and rubidium, and a fatty oil like arachis oil (Reed, 1976). Seeds also contain 9.6% moisture, 6.4% ash, 20.4% fatty oil, 21.4% nitrogenous matter, 15.7% saccharifiable matter, 12.9% crude fiber, and 13.9% other matter.



Kenaf

The main uses of kenaf fibre have been rope, twine, coarse cloth (similar to that made from jute), and paper. In California, Texas, Louisiana and Mississippi 3,200 acres (13 km^2) of kenaf were grown in 1992, most of which was used for animal bedding and feed.Uses of kenaf fibre include engineered wood, insulation, clothing-grade cloth, soil-less potting mixes, animal bedding, packing material, and material that absorbs oil and liquids. It is also useful as cut bast fibre for blending with resins for plastic composites, as a drilling fluid loss preventative for oil drilling muds, for seeded hydro mulch for erosion control.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Methods and Procedures

Collection of raw materials

Kenaf (*Hibiscus cannabinus*) was used to manufacture cement bonded particle board. Kenaf was collected from a local cultivator just beside the Khulna University Campus. Ordinary Portland cement, Holcim was used as a binder, purchased from local market.

Preparation of raw materials

The small branches and crown portion were removed by cutter. Then the Kenaf stem was kept under open sun for 2 weeks for drying. After that the narrow sticks were cut into small pieces by circular saw to feed into the chipper and kept under open sun for 15 days for drying.

Particle preparation

To produce particles of the Kenaf; chipping was done at the chipper machine. The small pieces of Kenaf stick were inserted into the chipper machine for producing different types of particles. From the chipper machine the particles were collected manually. Then it was dried to 12-14% moisture content.

Figure 3.1 Different particle sizes of Kenaf core

Mixing

The cement bonded particles boards were manufactured at cement/oven dry particle weight ratios of cement: particle: water = 2.2: 1: 1.1. This mixing condition was employed constantly through all of the following series of experiments. The additives added as a 10% of the cement weight. To obtain a uniform distribution of cement, particle and water, the mixing procedure was carried out systematically in a pan by mixing first cement and particles with required amount of water in to the particles. Mixing continued until the particles were covered completely with cement.

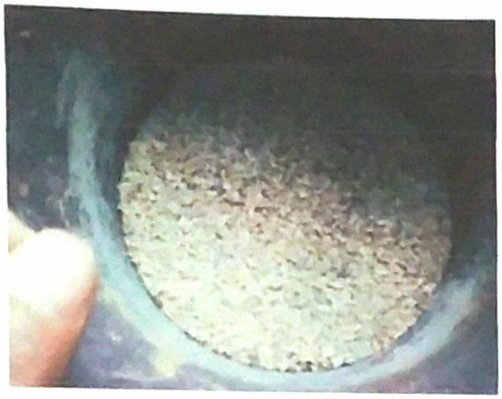


Figure3.2 mixing process of particles, cement and water

Mat forming

Each mixture was hand-formed into a rectangular of iron mould on a stainless steel plate lined with a superior quality polythene sheet to prevent the consolidated mat from sticking to the platen during pressing.

Figure 3.3 Mat forming process of wood cement board production

Cold pressing

Hand formed mats measuring 320×250 mm were cold pressed. It was kept in pressing condition for 24 hrs (Eusebio *et al.*, 1994).

Figure3.4 Cold pressing for CBP production

Curing

The cement bonded particleboards were cured in the conventional process. After pressing they were kept at room temperature for 14 to 30 days. Water was sprayed frequently for proper curing of the cement bonded particle board.

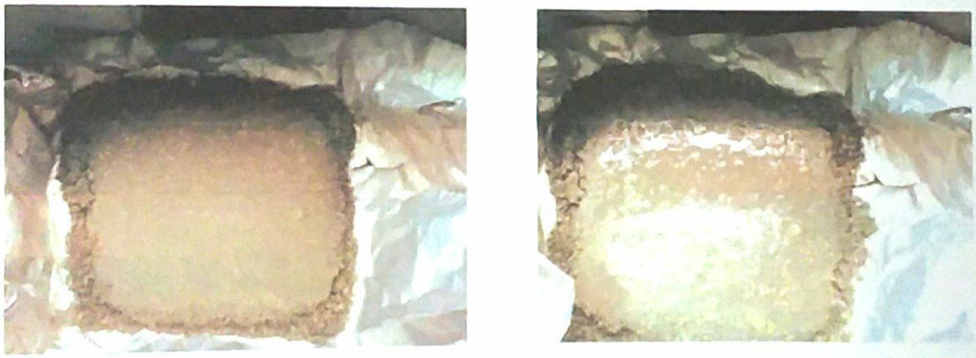


Figure 3.5 Curing process of CBP

Trimming

After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The dimensions of each type of boards were then 30 cm×20 cm.

3.2 Flow diagrams of Cement bonded particleboard production

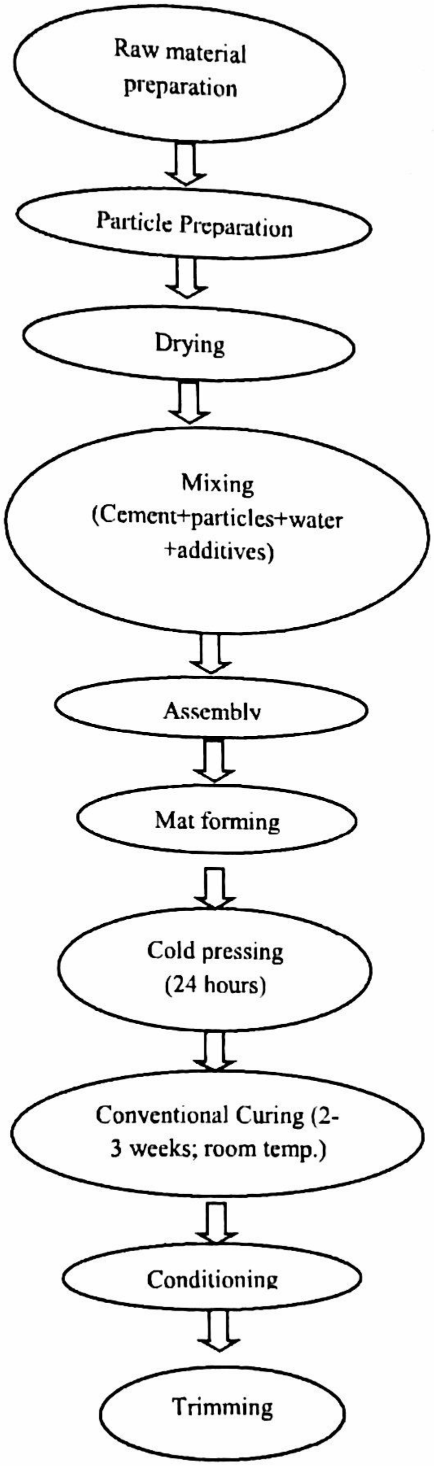


Figure 3.6 Flow diagrams of cement-bonded particleboard production

3.3 Specifications of manufactured Cement Bonded particleboards

Table 3.1: Specifications of manufactured Cement Bonded particleboards

Target Dimensions (mm)	250× 250
Target Density (gm/cm^3)	0.8-0.9
Used Chemical additives (Macl$_2$,NaHCO$_3$,Macl$_2$+NaHCO$_3$)	10 % of cement weight
Total no. of board manufactured	18
Ratios (Particle : cement: water)	(1: 2.2 :1.1)
Pressing	Cold
Particle size	Course, Fine

3.4 Preparation of samples for testing

Three replications of each type of boards were manufactured for testing physical and mechanical properties; three samples were collected from each board of each type.

The dimension of samples for testing the physical properties was approximately (5 cm x5 cm) and for testing the mechanical properties was approximately (25 cm x5 cm).

Figure3.7 Preparation of samples for testing

3.5 Analysis of Data

Completely randomized design was used in the experiment and all the data produced during the laboratory tests for characterization of physical and mechanical properties of each type of boards, were analyzed by using SAS-6.12(Statistical Analysis System) software. ANOVA (Analysis of Variance) and LSD (Least Significant Difference) were done to analyze the data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Density

The density of CBP for different particles size and different chemical additives treatments of UTF, UTC, TMF, TMC, TNF, TNC, TMNF and TMNC was 0.836, 0.818, 0.842, 0.834, 0.843, 0.835, 0.869 and 0.847 gm/cm^3 respectively. (Figure- 4.1).

The density of the board treated with $MgCl_2$+$NaHCO_3$(Fine) showed the highest value (0.869), the board treated with $NaHCO_3$ (Fine) showed second highest value (0.843), $MgCl_2$ (Fine) showed third highest value (0.842) and the untreated board(Course) showed the lowest value (0.818) for density. The variation in density among these types of cement bonded particleboards might be due to the addition of $MgCl_2$ and $NaHCO_3$ with cement-bonded particleboard. The variation in density for the different particles size might be due to the lower bulk density and higher compaction ratio. Lower bulk density and higher compaction ratio increased the density of the boards.

This is due to the fact that lower bulk density particles result in a higher compaction ratio, which will subsequently produce a higher strength panel than will higher bulk density particles (Suschsland & Woodson, 1990). In contrast, a higher proportion of course particles would result in a lower bulk density owing to the abundance of longer particles, which gives more compacted structures between particles (Xing *et al.*,2006).So that finer particles gave more density than the course particles.

From the analysis of variance (Appendix 6), it has been observed that the F value is 22.18 with 2 degree of freedom and 95% level of significance, which is greater than the tabulated value 3.4. Therefore there was significant difference exist among the density of different types of board.

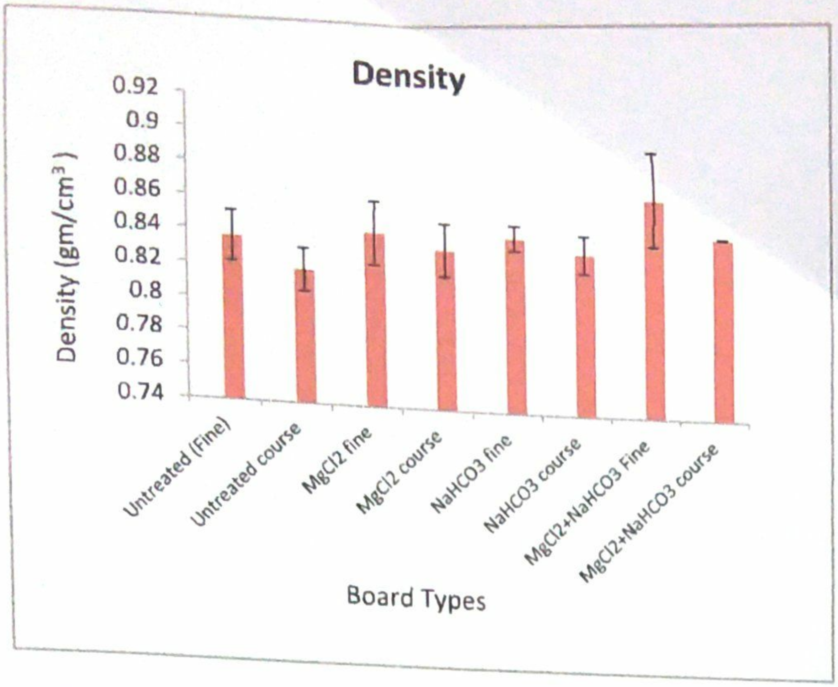


Fig 4.1: Density of cement bonded-board made from Kenaf core

4.2 Modulus of Rupture (MOR)

The modulus of rupture (MOR) of CBP for different particles size and different additives treatment of UTF, UTC, TMF, TMC, TNF, TNC, TMNF and TMNC was 9.55 N/mm^2, `11.95 N/mm^2, 13.59 N/mm^2, 15.85 N/mm^2, 12.92 N/mm^2, 14.47 N/mm^2, 17.9 N/mm^2 and 21.83 N/mm^2 respectively (Figure-4.2)

The MOR of the board treated with $MgCl_2$+$NaHCO_3$ (Course) showed the highest value (21.83) for MOR, the board treated with $MgCl_2$ (Course) showed second highest value (15.85), $NaHCO_3$ (Course) showed third highest value (14.47) and the untreated board (Fine) showed the lowest value (9.55) for MOR. The variation in MOR among these types of cement bonded particleboards might be due to the combine effect of magnesium chloride and sodium hydrogen carbonate. The initial setting of cement is accelerated by the addition of sodium carbonates and hence improvements in the hydration rates and the board properties. Cement hydration was not improved during water soaking because the $Ca(OH)_2$ and CO_2 generated from the cement clinker and the sodium hydrogen carbonates respectively may have reacted to form $CaCO_3$ that covered the cement clinker and prevented further hydration. The hydration of cement under water soaked condition was also accelerated by the addition of $NaHCO_3$ in combination with $MgCl_2$. The effects of these additive combinations improved the mechanical properties of CBP (Ma *et al.*, 1996). For the same reason untreated board showed lower MOR than $MgCl_2$ and $NaHCO_3$ treated board.

Specific MOR value for untreated board was 11.95 N/mm^2 whereas specific MOR value for ($MaCl_2$+$NaHCO_3$) was 21.83 N/mm^2. So MOR increased 48.34% when treated with ($MaCl_2$+$NaHCO_3$) which was almost double. This may be due to the higher hydration rate and internal bonding combination effect of $MaCl_2$+$NaHCO_3$.

The MOR of bamboo-cement board (Sulastiningsih, 1996) at a density of .89 g/cm^3 was 8 MPa. Compared to bamboo-cement board, the MOR of boards made from Kenaf core was comparatively higher than the bamboo-cement board. According to properties of cement-bonded board from oil palm fronds (Hermawan, 2001) the MOR of the board made from oil palm fronds (at a cement/wood ratio of 2.2:1.0 and treated with 7.5% $MgCl_2$) was 23.3 MPa. Compared to oil palm-cement board the MOR of the board made from Kenaf (at a ratio of wood/cement of 2.2:1.0 and treated with 10% $MaCl_2$) was lower. Hence the MOR of the board treated with combination of ($MaCl_2$+$NaHCO_3$) was almost similar to the board made from oil palm fronds.

The variation in MOR for different particles size might be due to the higher slenderness ratio and higher compaction ratio. Higher slenderness ratio and higher compaction ratio increase the MOR of the boards. The course particles have a greater slenderness ratio and better inter particle bonding, which resulted in high MOR values. This is in agreement with Barnes (2001) and Yadama (2002), who found that particles must be sufficiently long to allow adequate overlap for transfer of applied stress from one particle to the next. An increase in slenderness ratio results in a stiffer and stronger board in bending, but a decrease in internal bond strength (Moslemi, 1974), because mechanical interlocking only plays a major role in the bonding mechanism (Ahn & Moslemi, 1980) and chemical adhesion does not have an effect on this mechanism.

From the analysis of variance (Appendix 6), it has been observed that the F value is 369.98 with 2 degree of freedom and 95% level of significance, which is greater than the tabulated value 5.14. Therefore there was significant difference exist among the modulus of rupture of untreated, treated with $MaCl_2$, treated with $NaHCO_3$ and treated with ($MaCl_2$+$NaHCO_3$) CBP

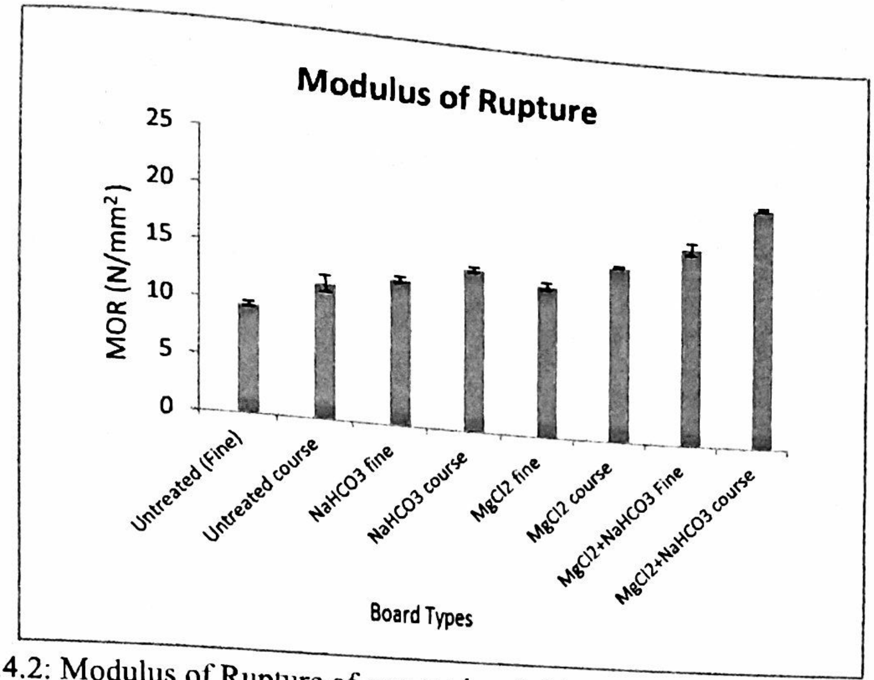


Fig.4.2: Modulus of Rupture of cement-bonded board made from Kenaf core

4.3 Modulus of Elasticity (MOE)

The modulus of elasticity (MOE) of CBP for different particles size and different chemical additives treatments of UTF, UTC, TMF, TMC, TNF, TNC, TMNF and TMNC was 3529.07 N/mm^2, `3709.44 N/mm^2, 4223.41 N/mm^2, 4638.96 N/mm^2, 4018.40 N/mm^2, 4313.24 N/mm^2, 5154.33 N/mm^2 and 5754.61 N/mm^2 respectively (Figure- 4.3).

The MOE of the board treated with $MgCl_2$+$NaHCO_3$ (Course) showed the highest value (5754.61) for MOE, the board treated with $MgCl_2$ (Course) showed second highest value (4638.96), $NaHCO_3$ (Course) showed third highest value (4313.24) and the untreated board (Fine) showed the lowest value (3529.07) for MOE. The variation in MOE among these types of cement bonded particleboards might be due to the production of high calcium carbonate ($CaCO_3$) content during the hydration process of cement. $CaCO_3$ provides the initial strength necessary for the board taken early out of the press. The variation that was found in MOE among the different types of CBP may be due to the same reasons for variation in MOR among the different types of particleboards.

The specific MOE value for untreated, treated with $MaCl_2$, $NaHCO_3$ and ($MaCl_2$+$NaHCO_3$) were 3709.44, 4638.96, 4313.24 and 5754.61 N/mm^2 respectively. MOE increased 20.61%, 16.61% and 42.87% from untreated board when treated with $MaCl_2$, $NaHCO_3$ and ($CaCl_2$+$NaHCO_3$) respectively.

The variation in MOE for different particles size might be due to the same reasons for variation in MOR among the different types of particleboards. Higher slenderness ratio and higher compaction ratio increase the MOE of the boards. With decreasing size, the wood particles are not completely coated by cement, which results in low bonding and therefore in MOE values.

From the analysis of variance (Appendix 6), it has been observed that the F value is 83.69 with 2 degree of freedom and 95% level of significance, which is greater than the tabulated value 5.14. Therefore there was significant difference exist among the modulus of elasticity of untreated, treated with $MaCl_2$, treated with $NaHCO_3$ and treated with ($MaCl_2$+$NaHCO_3$) CBP

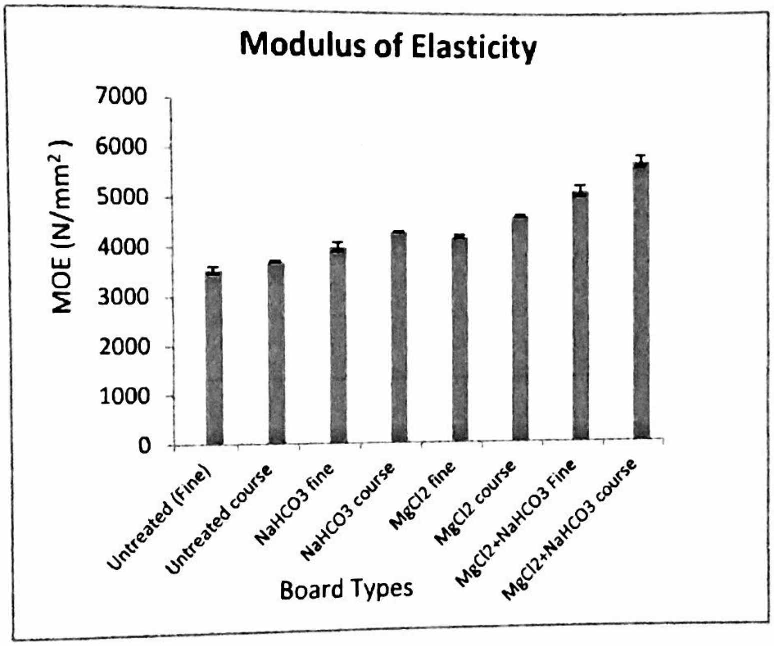


Fig.4.3: Modulus of Elasticity of cement-bonded board made from Kenaf core

4.4 Thickness swelling

The Thickness swelling of CBP for different particles size and different additives treatments of UTF, UTC, TMF, TMC, TNF, TNC, TMNF and TMNC was 9.64 %, `8.66 %, 6.06 %, 5.14 %, 3.84 %, 3.48 %, 1.63 %, 1.42 % respectively (Figure- 4.4).

The thickness swelling of the board treated with $MgCl_2$+$NaHCO_3$ (Course) showed the lowest value (1.42) for thickness swelling, the board treated with $NaHCO_3$ (Course) showed second lowest value (3.48), $MgCl_2$ (Course) showed third lowest value (5.14) and the untreated board (Fine) showed the height value (9.64) for thickness swelling. The variation in thickness swelling among these types of cement bonded particleboards might be due to the compounding effect of high internal bond (IB) strength of $MgCl_2$+$NaHCO_3$ treated board (Hermawan and Kawai, 2000). For the same reason untreated board shows higher thickness swelling than $MgCl_2$ and $NaHCO_3$ treated board. The variation in thickness swelling for different particles size might be due to the lower internal bonding (IB) capacity and higher porosity. Lower IB capacity and higher porosity increased the TS of the boards.

By using small particles, the particles are not encapsulated by cement, which results in low bonding and therefore in low internal bond values and increased TS (Del Menezzi *et al.*, 2007).

From the analysis of variance (Appendix 6), it has been observed that the F value is 10.5 with 2 degree of freedom and 95% level of significance, which is greater than the tabulated value 3.4. Therefore there was significant difference exist among the thickness swelling of different types of board.

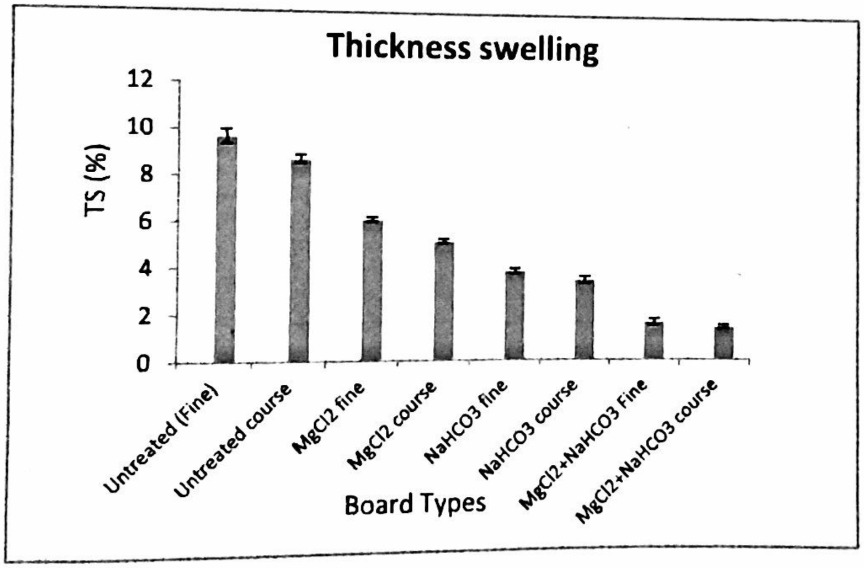


Fig.4.4: Thickness swelling of cement-bonded board made from Kenaf core

4.5 Water absorption

The water absorption of CBP for different particles size and different additives treatments of UTF, UTC, TMF, TMC, TNF, TNC, TMNF and TMNC was 39.88 %,42.42 %, 21.86 %, 23.11 %, 27.48 %, 34.18 %, 17.41 %, 20.34 % respectively (Figure- 4.5).

The water absorption of the board treated with $MgCl_2$+$NaHCO_3$(Fine) showed the lowest value(17.41) for water absorption, the board treated with $MgCl_2$ (Fine) showed second lowest value(21.86), $NaHCO_3$ (Fine) showed third lowest value(27.48) and the untreated board(Course) showed the height value(42.42) for water absorption. The variation in water absorption among these types of cement bonded particleboards might be due to the compounding effect of high internal bond (IB) strength of $MgCl_2$+$NaHCO_3$ treated board (Hermawan and Kawai, 2000). For the same reason untreated board absorbed higher amount of water than $MgCl_2$ and $NaHCO_3$ treated board. The variation in water absorption for different particles might be due to the lower bulk density and higher porosity. Lower bulk density and higher porosity increased the water absorption capacity of the boards.

The WA of boards increased as the fraction size of particles increased. This could be attributed to their lower bulk density for longer particles and hence higher porosity (Olorunnisola, 2009). Conversely shorter particles make denser structure between particles and porosity between particles decreases (Xing *et al.*, 2006). So that course particles gave more WA than the finer particles.

From the analysis of variance (Appendix 6), it has been observed that the F value is 147.69 with 2 degree of freedom and 95% level of significance, which is greater than the tabulated value 3.4. Therefore there was significant difference exist among the water absorption of different types of board.

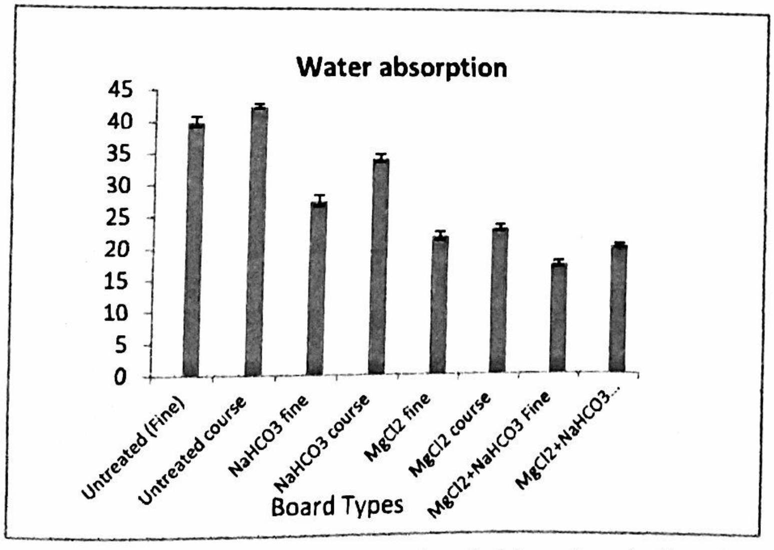


Fig.4.5: Water Absorption of cement bonded-board made from Kenaf core .

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Appendix 1: The Density of CBP for different particles size and different chemical treatments are given below:

Untreated course	
Sample	**Density**
sample 1	0.832
sample 2	0.827
sample 3	0.796
Average	0.818

Untreated fine	
Sample	**Density**
sample 1	0.872
sample 2	0.837
sample 3	0.801
Average	0.836

$Mgcl_2$ course	
Sample	**Density**
sample 1	0.806
sample 2	0.868
sample 3	0.83
Average	0.834

$Mgcl_2$ Fine	
Sample	**Density**
sample 1	0.816
sample 2	0.878
sample 3	0.832
Average	0.842

$NaHCO_3$ course	
Sample	**Density**
sample 1	0.816
sample 2	0.858
sample 3	0.831
Average	0.835

$NaHCO_3$ fine	
Sample	**Density**
sample 1	0.828
sample 2	0.86
sample 3	0.842
Average	0.843

$MgCl_2+NaHCO_3$ course	
Sample	**Density**
sample 1	0.846
sample 2	0.848
sample 3	0.849
Average	0.847

$MgCl_2+NaHCO_3$ fine	
Sample	**Density**
sample 1	0.798
sample 2	0.939
sample 3	0.871
Average	0.869

Appendix 2: The MOR of CBP for different particles size and different chemical treatments are given below:

Untreated course	
Sample	**MOR**
sample 1	11.95
sample 2	11.02
sample 3	12.88
Average	11.95

Untreated fine	
Sample	**MOR**
sample 1	9.12
sample 2	10.12
sample 3	9.52
Average	9.55

Mgl_2 course	
Sample	**MOR**
sample 1	15.85
sample 2	16.08
sample 3	15.53
Average	15.85

$Mgcl_2$ fine	
Sample	**MOR**
sample 1	13.15
sample 2	13.5
sample 3	14.13
Average	13.59

$NaHCO_3$ course	
Sample	**MOR**
sample 1	13.92
sample 2	14.65
sample 3	14.86
Average	14.47

$NaHCO_3$ fine	
Sample	**MOR**
sample 1	12.88
sample 2	13.3
sample 3	12.56
Average	12.92

$MgCl_2+NaHCO_3$ course	
Sample	**MOR**
sample 1	21.88
sample 2	22.01
sample 3	21.62
Average	21.83

$MgCl_2+NaHCO_3$ fine	
Sample	**MOR**
sample 1	17.33
sample 2	17.52
sample 3	18.87
Average	17.9

Appendix 3: The MOE of CBP for different particles size and different chemical treatments are given below:

Untreated course

Sample	**MOE**
sample 1	3670.96
sample 2	3752.25
sample 3	3705.12
Average	3709.44

Untreated fine

Sample	**MOE**
sample 1	3602.17
sample 2	3582.92
sample 3	3402.12
Average	3529.07

Mgl$_2$ course

Sample	**MOE**
sample 1	4880.32
sample 2	4533.98
sample 3	4502.58
Average	4638.96

Mgcl$_2$ fine

Sample	**MOE**
sample 1	4328.13
sample 2	4289.98
sample 3	4052.12
Average	4223.41

NaHCO$_3$ course

Sample	**MOE**
sample 1	4288.92
sample 2	4298.12
sample 3	4352.68
Average	4313.24

NaHCO$_3$ fine

Sample	**MOE**
sample 1	4019.91
sample 2	3985.2
sample 3	4050.1
Average	4018.4

MgCl$_2$+NaHCO$_3$ course

Sample	**MOE**
sample 1	5726.12
sample 2	5901.13
sample 3	5636.59
Average	5754.61

MgCl$_2$+NaHCO$_3$ fine

Sample	**MOE**
sample 1	5129.87
sample 2	5302.15
sample 3	5030.98
Average	5154.33

Appendix 4: The Thickness swelling of CBP for different particles size and different chemical treatments are given below:

Untreated course	
Sample	**TS**
sample 1	8.79
sample 2	8.3
sample 3	8.9
Average	8.66

Untreated fine	
Sample	**TS**
sample 1	9.12
sample 2	9.62
sample 3	10.2
Average	9.64

$Mgcl_2$ course	
Sample	**TS**
sample 1	5.28
sample 2	5.19
sample 3	4.97
Average	5.14

$Mgcl_2$ fine	
Sample	**TS**
sample 1	6.19
sample 2	5.87
sample 3	6.12
Average	6.06

$NaHCO_3$ course	
Sample	**TS**
sample 1	3.19
sample 2	3.68
sample 3	3.58
Average	3.48

$NaHCO_3$ fine	
Sample	**TS**
sample 1	4.02
sample 2	3.87
sample 3	3.65
Average	3.84

$MgCl_2+NaHCO_3$ course	
Sample	**TS**
sample 1	1.43
sample 2	1.28
sample 3	1.57
Average	1.42

$MgCl_2+NaHCO_3$ fine	
Sample	**TS**
sample 1	1.35
sample 2	1.87
sample 3	1.68
Average	1.63

Appendix 5: The water absorption of CBP for different particles size and different chemical treatments are given below:

Untreated course	
Sample	**WA**
sample 1	42.2
sample 2	43.19
sample 3	41.87
Average	42.42

Untreated fine	
Sample	**WA**
sample 1	40.19
sample 2	38.26
sample 3	41.2
Average	39.88

$Mgcl_2$ course	
Sample	**WA**
sample 1	24.25
sample 2	22.89
sample 3	22.19
Average	23.11

$Mgcl_2$ fine	
Sample	**WA**
sample 1	22.19
sample 2	23.2
sample 3	20.19
Average	21.86

$NaHCO_3$ course	
Sample	**WA**
sample 1	33.28
sample 2	34.19
sample 3	35.09
Average	34.18

$NaHCO_3$ fine	
Sample	**WA**
sample 1	28.36
sample 2	26.21
sample 3	27.89
Average	27.48

$MgCl_2+NaHCO_3$ course	
Sample	**WA**
sample 1	20.23
sample 2	19.87
sample 3	20.92
Average	20.34

$MgCl_2+NaHCO_3$ fine	
Sample	**WA**
sample 1	16.78
sample 2	18.26
sample 3	17.19
Average	17.41

Appendix 6: ANOVA test result for the physical and mechanical properties of the boards.

Source	Source	df	Calculated value	Tabulated value
Density	Treatment df	2	22.18	3.4
	Error df	24		
Water absorption	Treatment df	2	147.69	3.4
	Error df	24		
Thickness swelling	Treatment df	2	10.5	3.4
	Error df	24		
MOR	Treatment df	2	369.98	5.14
	Error df	6		
MOE	Treatment df	2	83.69	5.14
	Error df	6		