

**Effect of Some Treatments and Cement/wood ratio on
the Quality of Mesquite (*Prosopis chilensis*) Wood-
cement Aggregates.**

By

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Dedication

In the name of Allah, the Passionate and the Merciful
To all members of my family;

My father **Ali** who has encouraged me to love learning and knowledge and who was offering his endless help and support;

My mother **Bint Elneel** who taught me the rudiments of the alphabet and surrounded me with her love, care and tenderness;

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ABSTRACT

Effect of Some Treatments and Cement/wood ratio on Quality of mesquite (*Prosopis chilensis*) wood/cement aggregates.

Portland cement is an inorganic binder that can be used for the production of composite panels. Many studies have focused on understanding the complex behavior of wood-cement water mixture. Wood-cement panels are commanding renewed interest because of their potential application in building etc; they have specific advantages over conventional resin bonded particleboard which include resistance to outdoor exposures, fire, insects and rots.

This work was designed to study the compatibility of mesquite (*Prosopis chilensis*) wood with ordinary Portland cement for production of wood-cement aggregates. The wood materials used for this experiment was derived from *Prosopis chilensis* (mesquite) collected from Bara area, Northern Kordofan state. The experimental part of this study consisted of four main experiments; the promising results obtained in the former experiments will be used in the latter one. All experiments were conducted using Completely Randomized Design (CRD) with three-five replicates.

The first experiment was designed to study the extractive content of mesquite wood (solubility) using cold, hot water and mild alkali extraction methods. The alkali used was Sodium hydroxide with two concentrations (0.5 and 1) %. There were significant differences between the extraction methods. The greatest amounts of extractives were obtained when using 1% NaOH followed by 0.5% NaOH.

The second experiment was designed to determine the suitable treatment/s to be applied for mesquite wood to improve its compatibility with ordinary Portland cement. The treatments used were: soaking in cold water for 14 days; soaking in Sodium hydroxide solution (0.1%) for 24 hours, addition of calcium chloride as 3% based on cement weight and addition of gypsum as

20% based on cement weight. Untreated wood was used as control to compare the effect of above mentioned treatments. The results showed that the best treatment was the addition of gypsum followed by calcium chloride and control as indicated by the compressive strength of the aggregates. This indicates that mesquite wood can combine well with cement without treatments.

The Third experiment was designed to study the effect of cement- wood ratio namely 2:1; 3:1; 4:1 and 5:1. As the ratio increased all the studied variables (density, compressive strength, and water absorption) were improved, and the aggregates produced with cement wood ratio of 3:1 were found to have reasonable weight, good strength and reliable density. This implies that 3:1 cement wood ratio is the suitable and recommended ratio to be used for untreated mesquite wood.

The fourth experiment was designed to study the effect of cement replacement by gypsum as 10, 20, 30 and 50 percent based on cement weight using the recommended cement-wood ratio (3:1) that obtained in the third experiment results. Generally lower replacement percentages (10, 20%) were found to improve the compressive strength and water absorption, while increasing the replacement percentages more than 20% caused reduction in the density of the aggregates which negatively affect the compressive strength of the aggregates.

ملخص الاطروحة

أثر بعض المعاملات والنسب علي جودة خليط خشب المسكيت الأسمنتي

أجريت العديد من الدراسات لمعرفة السلوك المعقد لخليط الاسمنت والخشب والماء. الاسمنت البورتلاندي يعتبر احد المواد غير العضوية التي تستخدم في صناعة الالواح المكونه من الخليط . وجدت هذه الالواح حديثا رواجاً نسبة لاهميتها في عملية البناء ومن محاسنها مقاومة للعوامل الخارجية الضارة ، الحريق، الحشرات والتعفن.

تم تخطيط هذا العمل لدراسة مدي توافق خشب المسكيت مع الاسمنت البورتلاندي العادي لانتاج خليط الخشب الاسمنتي . المادة الخشبية المستخدمة في هذه التجربة تم الحصول عليها من شجرة المسكيت التي جمعت من منطقة بارا بولاية شمال كردفان.

احتوي الشق العملي لهذه الدراسة علي اربع تجارب رئيسة، النتائج الواعدة التي تم الحصول عليها من التجارب الأولى استخدمت في التجارب اللاحقة. كل التجارب نفذت باستخدام التصميم الأحصائي كامل العشوائية بثلاثة-خمس مكررات..

صممت التجربة الاولى لدراسة محتوى مستخلص خشب المسكيت (بالإذابة) باستخدام طرق الماء البارد، الماء الساخن وطرق الاستخلاص بالقلوي المخفف. القلويات التي استخدمت هي هيدروكسيد الصوديوم بتركيز (0.5 و 1%) . كانت هنالك فروقات معنوية بين طرق الإستخلاص، لكن اكبر كمية استخلصت عند استخدام 1% هيدروكسيد الصوديوم تليها 0.5% هيدروكسيد الصوديوم.

صممت التجربة الثانية لتحديد انسب معاملة او معاملات لتطبيقها علي خشب المسكيت لتحسين توافقها مع الاسمنت البورتلاندي العادي. المعاملات المستخدمة كانت غمر في الماء البارد لمدة اربعة عشر يوماً وغمر في محلول هيدروكسيد الصوديوم ذو التركيز 1% لمدة اربع وعشرين ساعة؛ اضافة كلوريد الكالسيوم بمقدار 3% من وزن الاسمنت ثم إضافة الجبص بمقدار 20% من وزن الاسمنت. الخشب غير المعامل تم استخدامة كشاهد لمقارنة اثر المعاملات المذكورة اعلاه. اوضحت النتائج ان افضل معاملة هي إضافة الجبص يليها كلوريد الكالسيوم ثم الشاهد وقد ظهر ذلك عند قياس قوة إنضغاط الخليط، وهذا يدل علي ان خشب المسكيت يمكن ان يعطي مكون جيد مع الاسمنت بدون اي معاملات.

صممت التجربة الثالثة لدراسة اثر نسب الاسمنت للخشب (1:2؛ 1:3؛ 1:4؛ 1:5). كلما زادت النسبة تحسنت كل المتغيرات التي درست (الكثافة؛ قوة الإنضغاط وإمتصاص الماء) لكن الخليط المنتج

باستخدام نسبة الاسمنت للخشب (3:1) وجد انه ذو وزن افضل وقوة جيدة وكثافة معقولة. وهذا يدل علي ان نسبة الاسمنت الي الخشب (3:1) هي النسبة المناسبة و التي يمكن ان يوصى باستخدامها لخشب المسكيت غير المعامل.

صممت التجربة الرابعة لدراسة اثر الإحلال الجزئي للاسمنت بالجبس بالنسب التالية (10 و 20 و 30 و 50%) اعتماداً علي وزن الاسمنت بإستخدام نسبة الاسمنت الي الخشب 3:1 الموصي بها والتي تم الحصول عليها من نتائج التجربة الثالثة. عموماً اقل نسب إحلال جزئي (10، 20%) وجدت انها تحسن قوة الإنضغاط وإمتصاص الماء، وكما زادت نسب الإحلال لاكثر من 20% و التي تسببت في نقص كثافة الخليط و التي تؤثر سلباً علي قوة الضغط.

CHAPTER ONE

INTRODUCTION

1.1 Background

A wood-cement particle composite is composed of wood particles, Portland cement and water. These composites have a history of several decades in the United States. The flexural strength of the wood-cement composite has been investigated extensively. Little to negligible information is available on the compressive strength of cement bonded wood particle composite. The use of wood-cement particle bricks in load bearing walls where the compression is solicited will require information on the compressive load and toughness as well. (Gong *et al.* 1993). Portland cement is an inorganic binder that can be used for the production of composite panels. Many studies have focused on understanding the complex behavior of a wood-cement-water mixture (Sandermann *et al.*, 1960; Simatupang 1979; Moslemi 1980; Miller 1987). At present time, wood-cement panels are experiencing renewed interests because of their potential application in the building industry (Dinwoodie 1983). They have specific advantage over conventional resin-bonded particleboard which includes resistance to fire, insects and rots. Also they have advantages of light weight over normal concrete. But cement-wood bonded products can not pass without problems; one of these problems is the poisoning effect of wood extractive on cement setting process (Parameswaran *et al.*, 1977; Parameswaran 1979). The extractives are more abundant in hardwoods than in softwoods (Gnannaharan and Dhamodaran, 1985). Many Sudanese hardwood species contain a

verity of extractive that expected to cause problems in cement setting. The knowledge of extractive content of these species will help to predict to a certain extent the suitability of various species for production of cement bonded products.

Mesquite (*Prosopis chilensis*) is one of these species. It colonized many habitats in different part of Sudan and is utilized only for fire wood. Several efforts were made to control mesquite, but they were not sustainable as long term funding has never been guaranteed. A programme of uprooting of mesquite was initiated by the federal ministry of agriculture in 1995. A- programme for containment of mesquite was planned in New Halfa in 1996, with little success (El Tayeb, et al., 2001).

A programme, Food for Work, was run by Oxfam to control mesquite in Tokar delta. Under, the programme families of low income were mobilized to the delta, offered food and two hectares for each family of mesquite infested land for peating up the mesquite trees. Mesquite pods were swapped for sorghum to encourage collection and prevent mesquite spreading.

In 1996 the government approved a bill on mesquite management. The tree is to be eradicated where it constitutes a threat to agriculture or biodiversity and preserved in areas threatened by desertification. At present active eradication programmes, using both mechanical and manual methods for uprooting mesquite, are implemented in New Halfa agricultural scheme and Tokar delta at costs of 7.4 and 8.7 million US dollars, respectively. A similar eradication programme was implemented in Zeidab irrigated scheme. However, because of high cost eradication was incomplete and due to poor follow-up, a significant proportion of the cleared area is re-infested.

Work in progress at the Agricultural Research Corporation indicated that the herbicides triclopyr and clopyralid applied as aqueous sprays to foliage or in diesel formulations to the stem base displayed excellent activity against the weed.

This study is an attempt to find another way of utilizing mesquite wood (sap and heart wood) for production of cement bonded

aggregates.

The production of wood-cement panels is likely to increase in the future because of the availability of wood and cement in many countries.

Extractives present in mesquite wood are expected to cause problems of cement setting when producing cement wood bonded products.

There is a complete lack of information regarding the suitability of mesquite wood for the manufacturing of cement bonded products. As it is known that extractives of sapwood differ a bit from of heartwood so it may be less harmful to cement setting process. Also such study will pave the way for finding one way or another for utilizing mesquite wood. This helps in finding one way of combating or controlling mesquite spread through its management for production of raw materials for production of cement bonded products.

1.2 Overall objectives

The overall objective of this work is to study the compatibility of mesquite wood (*Prosopis chilensis*) wood with ordinary Portland cement and its suitability for the production of wood-cement aggregates.

1.3 Specific objectives

1. To study the effect of extraction methods on the amount of extractives of mesquite wood (sapwood and heartwood).
2. To investigate the effect of different pretreatments on mesquite wood-cement compatibility.
3. To investigate the effect of cement-wood ratios on the

performance of mesquite wood-cement aggregates.

4. To study the effect of partial replacement of cement by gypsum using a fixed cement-wood ratio.

CHAPTER TWO

LITERATURE REVIEW

2.1 History

Cement is perhaps the most widely used and versatile composite matrix materials. In its most common form, cement is combined with stone (gravel) aggregates to improve compressive strength and durability. Steel reinforced bars improve bending capacity and resistance to crack. Fiber reinforcement has also been used to improve fracture toughness. The best known and most widely used material of this type is cement asbestos boards, which has been used as roofing and siding material throughout the world for nearly 80 years. Wood-cement composites are generally categorized into two categories: wood particle-cement composites and wood fiber-reinforced cement products. Wood particles-cement composites have been in use as architectural, fire-resistant, and acoustic panels while wood fiber-reinforced cement products were primarily used as substitute for asbestos-cement composites and are relatively new. They were developed and promoted mostly in 25 to 30 years. (Wolfe, Gjinolli 1997).

The idea of using cement as a binder for composite panels is not new. According to Elten (2000), its origin goes back to the beginning of the 20th century, in Austria. However, it was necessary to wait until the middle of the century for the installation of the first automated lines. Since then, production plants have been established all around the world, even in developing countries. However, Canada and the United States were behind Europe and Asia, with only a few small plants in

operation (Elten 2000).

2.2. Type and uses of cement bonded products

There are different types of mineral- bonded products; wood-wool, building blocks, cements bonded flakes or particleboards and cement fiberboards.

2.2.1 Wood-wool cement board (WWCB)

The first cement bonded boards, were produced in 1928 in Germany. The binding agent used before World War II was a mixture of cement, magnesite and gypsum with ratio of 39%, 35% and 26% respectively, (Maloney 1989). After the War cement became the dominant binder in Europe. The technology of the process has been highly developed and properties were standardized. Wood wool cement board is a universal material. It can be produced in high technology plants as well as smaller local plants.

The manufacture of wood wool requires particles with specific and defined dimensions; length range between 25-500 mm, width range between 0.5-5 mm and thickness between 0,03-0.64 mm (Maloney 1989).

The shredded wood is then treated with CaCl_2 and mixed with Portland cement/wood ratio 2:1 based on an oven dry weight of wood material. The mixture is spread onto plywood or metal mould solid conveyors or belts and stacked. The mats are then pressed at room temperature under a pressure of about 10 pounds per square inch. The stack is clamped under pressure for a bout 24 hours and then removed from the moulds and cured in water for 2-4 weeks. The boards are then trimmed and finished. (Anonymous, 2001).

2.2.2. Cement-bonded Particle board (CPB)

Heavy weight wood cement boards were developed by Elmendorf Research Inc, in America (Stillinger and Wentworth 1977). The concept of a high-density board using chips was taken up and developed in Switzerland with slight modifications. After successful tests at official laboratories, both in Switzerland and in Federal Republic of Germany, an automated wood-cement particleboard plant was built by Bison-Werke, a German supplier of particleboard plants. Cement bonded particleboard was well established it self in Switzerland and central Europe by mid-1970s (Dinwoodie 1996). Cement bonded particleboard differs from wood wool cement board in that the wood is in particles rather than strands. The finished boards are usually much wider and pressed to a higher density of about 1250 Kg/m³. The production of such boards generally requires higher technology equipment since the boards are required to comply with strict international standards concerning their bending strength properties and thickness tolerances (Anonymous, 2001).

2.2.3. Building Block

Building blocks using cement as a binder for wood particles has been used for many years. This type of product has been popular in Scandinavia. A number of buildings were constructed with this type of material in the United States. A pilot plant has been built in Spokane, Washington, where the block is fabricated by machine. The size of the boards produced is about 203mm thick, 305mm high and 1.21m long. The machines can produce larger blocks with desirable height and thickness. Also, toughed and grooved block can be made

for the do it your self builder. The large size blocks weigh approximately 45.5 Kg and compare favorably to the weigh of a similar pieces of wood of about a same size. The blocks have excellent insulation properties. Most of its working properties such as nailing, sawing, drilling and siding are much like any piece of soft wood. Because of the ease of manufacturing, this building blocks are not suitable for some operations in developed countries but an excellent product for production in developing countries (Mallony 1989).

2.3. Wood cement compatibility

The compounds that constitute Portland cement are usually present in the form of oxides. The basic elements are Iron and aluminum. The existence of only one of the two is required for production of cement (Moslemi 1974). The ability of wood to combine with cement is termed wood cement compatibility. When Portland cement is used as binder with wood, we faced some problems. Many wood species contain a number of substances (mainly organic in nature) which have deleterious effects on wood-cement bonding. In severe cases, they inhibit cement setting in spite of the length of time allowed. These substances had been reported to be more abundant in hardwoods than in softwoods (Ibrahim 1993). Many researchers have developed methods to classify different wood species according to their compatibility with cement. There were different methods to evaluate the compatibility, but they lacked consistency. In the classification of some species will be depend on the classification of methods used. These differences can be related to many causes, such as calorimeter,

the hydration condition and wood: cement: water mass ratio which are not constant or the same in the different methods (Hachemi *et al.* 1990).

2.4. Measurement of wood-cement compatibility

The evaluation of wood-cement compatibility can be made by measuring the mechanical properties of the panel produced (Yoshimoto 1978; Lee and Hong 1986). However, the majority of the compatibility tests are concerned with the comparison of kinetics of hydration of the wood-cement mixtures with that of pure or plain cement. This is done by measuring the temperature or the heat of hydration (Sandermann *et al.* 1960; Sandermann and Kohler 1964; Weatherwax and Tarkow 1964, 1967; Hofstrand *et al.*, 1984; Hachmi *et al.*, 1990; Miller and Moslemi 1991a, 1991b; Semple and Evans 1998, 2000; Sauvat *et al.*, 1999; Alberto *et al.*, 2000). The methods used are preceded either by adiabatic, semi-adiabatic, or isothermal calorimetry.

The recording of the hydration temperature makes it possible to classify various wood species and rank them according to their degree of inhibition of cement setting which used as indicator for their compatibility with cement. The interest of this method lies in the fact that the maximum temperature of hydration and time to reach this temperature depend on the species used, Sandermann and Kohler (1964) tested and classified 99 wood species, as compatible when (T_2) is higher than 60°C, intermediate when (T_2) ranges between 50°C and 60°C, and incompatible when (T_2) is lower than 50°C.

The inhibitory index developed by Weatherwax and Tarkow (1964)

compares the increase in time of setting of the wood-cement mixture with that of pure or plain cement. Data of maximum hydration temperature, and time to reach this temperature, as well as the maximum slope of the temperature curve versus time have allowed Hofstrand, *et al.*, (1984) and Moslemi and Lim (1984) to develop another inhibitory index which gives the inhibitory index calculated by these authors for some North American softwoods and hardwoods species. Species with a small inhibitory index are the most compatible, such as lodge pole pine (2.6) and western white pine (3.9); whereas species with a high inhibitory index, such as western larch (118.3) and red maple (212.4), are incompatible. According to Hachmi *et al.*, (1990), the inhibitory index developed by Hofstrand *et al.*, (1984) lacks consistency during the classification of the species, because of experimental conditions that vary from one laboratory to another. Therefore, they proposed to use the compatibility factor, (C_a), which is the ratio of the surface integral defined by the curve of heat of hydration versus time of the wood-cement mixture to that of pure cement. Previously, Hachmi and Moslemi (1989) used this factor to determine the relationship between the extractive content and the compatibility level. They grouped various species in three classes: the compatible species with a (C_a) higher than 68%, the moderately compatible species with a (C_a) between 28 and 68% and incompatible species with a (C_a) lower than 28%. Semple and Evans (1998, 2000) also used this factor as an index of compatibility of wood with cement. (C_a) is more reliable and makes it possible to classify species in a scale from 1 to 100 percent. However, measurements are made in

a dewar flask, which is not very sensitive to the thermal changes taking place in the mixture. Moreover, the temperature of hydration is measured and converted into heat of hydration, which involves knowledge of the heat capacity of the sample and of the Dewar flask. Conduction calorimeter, used in civil engineering laboratories to study the behavior of various types of cement (Bensted, 1987; Bhatta, 1991; Wadso, 2000) has been used by some researchers in the field of wood-cement panels (Sauvat, *et al.*, 1999; Alberto *et al.*, 2000). With this method, one measures directly the rate of heat production that proportional to the reaction rate of cement hydration. Thus, it is not required to know the heat capacity of the wood-cement-water mixture, nor that of the calorimeter. This method also has the advantage of being very sensitive to thermal changes during cement hydration. The compatibility factor in this case can be either the total enthalpy generated during the reaction (Sauvat, *et al.*, 1999) or the ratio of the total quantity of heat produced by the wood-cement mixture to that produced by plain cement (Alberto *et al.*, 2000). The only drawback of micro-calorimetry lies in the fact that measurements can only be made on very small samples, about 3 to 10 mg.

2.5. Mechanism of cement setting

Cement consists of numerous inorganic compounds, which set and harden in the presence of water. Portland cement type I (particle surface area $1600 \text{ cm}^2/\text{gm}$) contains tricalcium silicate ($3\text{CaO}\cdot\text{SiO}_2$) as the most dominant component. Hydration of tricalcium silicate starts promptly as soon as it comes in contact with water. The reaction leads to the production of calcium hydroxide. As the processes of hydration

proceed liberation of calcium hydroxide is the main product. The hydration of dicalcium silicate ($2\text{Ca}_2\text{O}.\text{SiO}_2$) advances only slowly with some lime liberation during the reaction. On the other hand, the hydration of tricalcium aluminates ($3\text{CaO}.\text{Al}_2\text{O}_3$) is more rapid; resulting in needle like crystals which continue to increase in size and amount with the progress of the hydration and is capable of rendering the material almost dry. Tetra calcium alumina-ferrite ($4\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$) hydrates with water, but not as the tricalcium aluminate, it shows good crystals formation in a day. Due to the above mentioned factors, the bond with Portland cement is generated through crystallization process with masses of interfaced crystal involved. It is believed that the hardening of cement is due to intergrowth of interlocked crystal (Moslemi 1974) although other widely different theories on the subject have been advanced (Lea 1965).

2.6. Inhibition Mechanism

Wood species have been classified as highly suitable, unsuitable and less suitable for the manufacture of wood-cement products, or as having non-inhibitory, moderately inhibitory or highly inhibitory effect on the curing of cement,(Hachemi and Moslemi 1989,Alberto, *et al.* 2000).The nature and quantity of wood component critically affect the cement hydration and composite strength. The exact cause of cement inhibition by wood components is difficult to ascertain, since a number of complex chemical and physical processes are occurring. Various compounds are thought to be responsible for the inhibitory effect of wood on cement setting including soluble sugars,

arabinogalactans, phenolic and other extractives, Geographical location, felling season and storage period also influence cement curing through their effects on the extractive content of wood (Yoshida *et al.*1992). Simple wood sugars may migrate to the surface during drying. Since these sugars contain hydroxyl and carboxylic acid functional groups, they may react with calcium, aluminum, and iron cations in the cement retarding its setting (Young, 1970) and perhaps disrupt the crystallization reaction (Mariampol and Skii *et al.* 1974). The latter increases 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 and setting, resulting in wood cement composite with inferior strength (Sandermann and Kohler, 1964). In addition, the hemicelluloses may undergo peeling reactions (Whistler and Miller 1958). In alkaline cement inhibitory sugar acid are formed (Fisher, *et al.* 1974), the acetyl groups present in the hemicelluloses are probably cleaved by the alkali to form potentially inhibitory metal acetate compound (Browning 1967; Goldstein 1984). Non-polar extractives such as terpenes, resins, and fats also migrate to the wood surfaces during the drying. The hydrophobic surface layer may reduce hydrogen bonding between wood and cement thus and weaken interfacial bond strength, phenolic compounds such as tannins also have capacity to complex with metal ions in cement and potentially inhibit normal hydration reactions (Bash and Rakhimbaev, 1973).

2.7. Factors affecting the compatibility of wood with cement

Wood cement mixtures suffer from some problems. Many constituents of wood cause delay on cement setting and at adverse conditions it completely inhibits cement setting. Many factors were reported to affect the compatibility of wood with cement. Among them: wood species, extractives, chemical additives, particle geometry, cement-wood ratio, amount of water.

2.7.1. Effect of the species

The effect of species depends mainly on the extractives present in wood species. The characteristics of nine softwood species of the northern Rocky Mountains mixed with Portland cement allowed Hofstrand, *et al.*, (1984) to classify them according to their level of inhibition. The results indicate that wood species are not equally compatible with cement. Lodge pole pine (*Pinus contorta*), western white pine (*Pinus monticola*), and grand fir (*Abies grandis*) have less effect on cement hydration, whereas Engelmann spruce (*Picea engelmanni*), western red cedar (*Thuja plicata*), and ponderosa pine (*Pinus ponderosa*) have a moderate effect on cement setting. Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) showed a high incompatibility; whereas western larch (*Larix occidentalis*) was strongly incompatible. Moslemi and Lim, (1984) studied the compatibility of some hardwood species with cement. Among the species studied, chestnut oak (*Quercus prinus*) proved to be least inhibiting; whereas red maple (*Acer rubrum*) was the most inhibiting. The compatibility of five native species of Taiwan was studied by Chen, *et al.*, (1998) and the results indicated that among these species, only teak (*Tectona grandis*) proved to be less inhibiting.

Yashido, *et al.*, (1992), studied the manufacturing conditions of cement bonded wood boards of *larix leptolpis*, *patula japonica*, and *petercarya rhoifolia* and concluded that the hydration temperature of wood cement mixture attained, varied with the species and between sapwood and hardwood.

Kamall and Suwandi, (1974) found that *Dipterocarpus graeillis*, *Shorea javanica* and *S.leprosula* were good and *Anthocephalus cadamba* (sapwood) was fair, while the heartwood of *Anisoptera marginata*, *Hopea mengarawan*, and *Vatcea spp*, were poor with regard to their suitability for wood wool cement boards. Pariborto, *et al.*, (1977) investigated the suitability of five Indonesian wood species for wood wool cement boards and cement bonded particleboard based on maximum hydration temperature, they found that *Cananga odorata*, *Ilex Pleibrachiata*, *Manglietia glance* and *Sloanea signum* were good while *Gossampinus malabarica* was fair.

Jain *et al.*, (1989) in his study of some softwoods, hardwoods and other lignocellulosic materials including agro waste, concluded that among the softwoods beside others, *Pinus wallichiana* and *Picea smithiana* were suitable; some of the hardwood such as *Eucalyptus camaldulensis*, and *Terminalia paniculata* were compatible with cement. Among the agricultural residues studied, rice husk-cement mixtures developed adequate strength.

Young and Moslemi, (1984) investigated the effect of hot water extraction treatment and addition of accelerators on the inhibitory index of eight Korean lignocellulosic materials. They found that the inhibitory index of *Pinus densiflora* and *Pinus rigida* were suitable under

limited conditions for composites without any treatment. They also found that six to eight lignocellulosic materials reached a maximum hydration temperature of less than 50°C. These species were suitable under limited conditions. They concluded that none of the species studied could be classified as highly suitable. Manzanares, *et al.*, (1989) investigated the suitability of three species namely, *Casuarina equisetifolia*, *Pinus tropicalis* and *Bursera simaruba*, by measuring the hydration temperature. They found that *C. equisetifolia* was very suitable, *P. tropicalis* was suitable and *B. simaruba* was unsuitable. Yasin and Quershi (1989) Studied eight hardwood species and indicated that poplar wood (*Populus spp.*) provides a better raw material for wood cement board than *Acacia nilotica*, followed by *Dalbergia sisso*, and *Tamarix aphylla*. Among the poplars, *P. alba* was better than *P. deltoids*, *P. cilicata* and *p. euphratica*. Lee and Hong (1986) stated that the compressive strength of wood and cement mixture depends primarily on the wood species used. They presented a simple compression test of cylindrical samples as indicator of wood cement compatibility. They indicated that compressive strength was linearly proportional to maximum hydration temperature, but independent of hydration time. They found that maximum hydration temperature ranged from 30°C to 33°C for green wood and 32°C to 51°C for air dried wood. The highly significant difference in hydration temperature was attributed to the differences between species. Hachmi and Moslemi, (1989) studied sixteen Moroccan wood species and concluded that species may have the same extractive content but different compatibility with cement. These indicate that the chemical composition of the

extractives also has an impact on compatibility. A number of researchers have shown that differences in behavior of species when mixed with cement are due to differences in cell wall substances (Biblis and lo 1968; Moslemi, *et al.*, 1983; Hofstrand *et al.*, 1984; lee, *et al.*, 1987; Kumar, 1980; Jain, *et al.*, 1989; and Hachmi, *et al.*, 1990). Oyagade, (1994) examined the compatibility of some Nigerian species with ordinary Portland cement and observed considerable differences between the species. *Gmelina arborea* was the most inhibitory to cement setting among the species examined. Ibrahim (1995) studied five species grown in Sudan and observed that the species effect was significant. The inhibitoriest species was *Acacia nilotica* and the least was *Eucalyptus camaldulensis*. Nasser, (1996) studied the compatibility of wood cement mixture of four wood species using hydration and compressive strength test. He found that poplar (*Populus spp.*) and European red wood (*Pinus sylvestris*) showed the highest value, while the lowest were obtained by *Casuarina gluca* and *Eucalyptus camaldulensis*. He concluded that poplar and European red wood can be used for cement panels without any treatment and chemical additives and are suitable under limited conditions, while *Casuarina* and *Eucalyptus* need some treatments. Moursi, (2002) stated that hydration characteristics and compressive strength test revealed that cotton stalks had low level of compatibility under untreated conditions.

2.7.2. Effect of wood Extractives

Wood affects the rate of cement setting to a greater or lesser degree. Farmer, 1967 and Hofstrand, *et al.*, 1984 indicated that, the inhibitory

effect of wood was attributed to the presence of different type of the extraneous materials present in the wood. Choi. *et al.*, (1984) investigated the effect of monosaccharide on cement setting by using the inhibitory index of some wood species widely reforested in Korea such as *Pinus koraiensis*, *Pinus rigida*, *Pinus densiflora* and agricultural waste of rice husks and rice straw. They concluded that the inhibitory index increased with increasing the ratio of the hexose's to pentoses. Liu and Moslemi, (1986) stated that water soluble wood extractives play a dramatic role in cement setting. Even small amount of extractives can be detrimental to cement hardening and subsequent development of strength properties of cement bonded composite boards. An experiment conducted by Liu and Moslemi, 1986 showed that almost all simple sugars examined and some other carbohydrates bring about a complete loss in strength of the cement when added in a amount as low as 0.25% by weight of cement. Tannins produced a similar effect (Miller, 1987). Hachmi and Moslemi, (1989) studied the correlation between wood cement compatibility and wood extractives using nine hardwood and softwood species. They indicated that different woods may have the same extractive content but different compatibility with cement.

Miller and Moslemi, (1991b) studied the effect of model compound on hydration characteristics and tensile strength; they concluded that model compounds representing cellulose, lignin, fatty acids and terpenes at 1.0% or less did not significantly decrease tensile strength. Glucose caused the greatest decrease in tensile strength. All hydration characteristics were substantially affected by sugars, tannins

hemicelluloses, tannins and hemicelluloses having the greatest effect.

2.7.3. Effect of wood treatment and additives

Wood and other lignocellulosic materials have been in use for ages in cement matrices for manufacturing construction products (Bentur and Mindess, 1990). These materials are added either in form of fibers or particles. Natural fiber exists in abundance and is readily available at low cost being derivable from various parts of tree material such as leaves, stems, fruit surface or wood. These fibers are usually incorporated into the cement matrix in discrete, discontinuous form. Their major role is to reinforce or delay and control tensile cracking of the matrix, with a view to achieving reduction in stress and imparting a well defined post-cracking and post yield behaviors (Swamy, 1990).

Wood particle-cement composites have been produced from a number of materials including sawdust, construction waste, bagasses, coffee husk, maize husk, and rattan furniture waste among others (Kasai, *et al.*, 1998; Olorunnisola and Adefisan, 2002). However, when particles from many woody materials come in contact with cement slurry, their organic compounds, such as carbohydrates, tannins, and flavonoids tend to retard or inhibit cement hydration and bond formation between the cement and wood particles. The effect is the slowing down of the strength development and delay in the demoulding of products (Biblis and Lo 1968; Zhengtian and Moslemi 1986; Hachmi and Campbell 1989; Swamy 1990; Miller and Moslemi 1991; Alberto, *et al.*, 2000). While the precise mechanism of cement setting due to wood particle is yet to be fully understood, several means of

minimizing the effect has been devised, including prolonged storage of the wood material, hot or cold water extraction of soluble sugars, and the use of chemical accelerators, namely dilute sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3), calcium chloride (CaCl_2) and aluminum sulphate $\text{Al}_2(\text{SO}_4)_3$ among others (Hong and Lee 1986; Badejo, 1989).

The use of CaCl_2 , has been reported by numerous researchers, some of whom reported that a dosage of less than 4% (by weight of cement), tends to accelerate the hydration of wood-cement mixtures thereby enhancing the wood-cement bond and the mechanical properties of the composites (Biblis and Lo 1968; Ahn and Moslemi, 1980; Zhentian and Moslemi 1985; Moslemi and Pfister 1987; Badejo 1988; Olorunnisola and Adefisan, 2002).

Many investigators carried a series of tests to improve the compatibility of wood and cement by using various treatments e.g. extraction or soaking of wood particles in some solutions such as hot water, and Sodium hydroxide before its mixing with cement. On the other hand, some investigators carried out a series of tests designed to improve the wood-cement mixture by addition of some chemicals such as calcium chloride and sodium hydroxide.

Different methods were tried by researchers to treat wood in order to enhance its compatibility with cement. The logs are usually stored for at least three months to neutralize the sugars (Dinwoodie and Paxton 1983 and Anonymous, 2001). Gnanaharan and Dhamodaran (1985) examined the effect of water extraction on the solubility of 13 tropical hardwoods for wood-wool-cement-board. They found that extraction

with cold water was sufficient to remove the inhibitory extractives from most of the tested species. Abdelgadir and Ibrahim (2002) indicated that treatment of wood with cold water improved wood compatibility with cement for all the species studied, except *Eucalyptus microtheca*. The addition of calcium chloride was associated with the highest compressive strength except for *Calotropis .procera* at low ratios. Hassan (1999) studied the effect of different levels of CaCl_2 on the properties of *Acacia nilotica* wood- cement mixture. She found that when wood was extracted, increasing the level of calcium chloride was associated with increase in strength properties. Nasser, (1996) stated that substantial improvement in cement setting can be achieved by using hot water and 1% NaOH solution extraction for *Eucalyptus* and *Casurina*. The addition of CaCl_2 (3% cement weight basis) for the four species studied, improved their compatibility with cement and species can be classified as highly suitable.

2.7.4. Effect of particle geometry

Wood geometry (shape and size) has a great effect on board characteristics such as water absorption, thickness swelling, linear stability, strength and surface smoothness. It also controls the behaviors of board to machining i.e. sawing, shaping, planing and sanding (Moslemi, 1974b).

For most forest products, density is an important physical attribute because it is correlated to most mechanical properties. Therefore, low density boards should be produced. Taking this into account, and strategies need to be developed such as altering the type and geometry of the particles and the type of mat forming to increase the

mechanical properties of the boards. Some authors present satisfactory results with low-density panels produced with flake-type particles (Pereira, 1987) as well as with excelsior-type particles (Miller, *et al.*, 1989). Excelsior seems to be ideal for the production of low density WCB, because it is a long and thin type of particle, which is ideal for the production of stronger and stiffer boards, as argued by Badejo, (1988).

2.7.5. Effect of cement/ wood ratio

Moslemi, (1986) studied the effect of cement/wood ratio and cement type on bending strength and dimensional stability of wood-cement composites. He found that decreasing cement to wood ratio from 3:1 to 1.5:1 increased modulus of rupture (MOR) from 15.1 MPa (155 Kg/cm²) to 16.3 MPa (166 Kg/cm²) for type I (ordinary Portland cement), and from 14.8 MPa (150.9 Kg/cm²) to 16.4 MPa (167.2 Kg/cm²) for type II (highly developed early strength Portland cement). However modulus of elasticity decreased from 5.35 MPa (54.5 Kg/cm²) to 3.6 MPa (36.7Kg/cm²) for type I and from 5.34 MPa (54.4 Kg/cm²) to 3.47 MPa (35.3 Kg/cm²) for type II when using the same cement/wood ratio.

Abdelgadir and Ibrahim (2003) concluded that compressive strength of wood-cement mixture is considerably reduced as cement/wood ratios were decreased for the five Sudanese species studied. Lee, (1984) stated that if a lower cement/wood ratio is used, wood excelsior will not receive adequate cement coating, which results in poor bonding. If a higher cement/wood ratio is used, the compaction ratio will be reduced, resulting in lower bending strength. Lee and

Hog (1986) reported that lower cement to wood ratio can be used when identifying suitable species under the influence of calcium chloride as an accelerator. Blankehorn, *et al.*, (1994) investigated the effect of hydration time, mild chemical modification, and cement to wood to mild ratio (from 13.3:0 to 13.3:5.5 by weight) on compressive strength of hardwood-cement composites. They found that as hydration time increased, the compressive strength increased. They also found that increasing the amount of hardwood furnish above the ratio of 13.3:2 was unsuccessful. Oyagade, *et al.*, (1995) reported that veneer laminated cement-bonded particleboard was stronger and stiffer with increased cement/wood ratio and density.

2.7.6. Effect of the mount of water used in wood cement mixture

When dealing with cement it is very important to bear in mind that the cement mixture should not exceeds the cement saturation point. This usually happen when using improper amount of water. This is the main reason that drives many researchers around the world to investigate the proper amount of water to be added to a cement wood mixture. For example Weatherwax and Tarkow, (1964, 1967) suggested that 2.7 ml of water for each gram of wood (oven-dry-wood) and 0.25 ml of water for each gram of cement is suitable. The work of Oyagade (1990) held the mount of water for blending at 25% of the mass of cement. He indicated that theoretically dry cement requires amount of water equivalent to 23% of its own weight for hydration process. According to Basher, (2005) the quantity of water added was calculated using a relationship developed by Simatupang, (1979). The water required was determined as fallows:

Amount of water (liter) = $0.35 + (0.3C - MC) * W_o$

Where:-

C = Cement weight (Kg)

MC = Moisture content of wood (Oven-dry basis)

W_o = Oven dry weight of wood (Kg).

2.8. General description of mesquite trees

2.8.1. Morphology

Prosopis chilensis is a small to medium sized tree up to 12 m in height and 1 m in diameter; bark brown, fissured; spines a pair, stout, yellow, glabrous; root system reportedly shallow and spreading. The leaves are compound, each with numerous leaflets along several pairs of pinnae. *P. chilensis* has 10-29 leaflets per pinnae and no more than two pairs of pinnae per leaf. The leaflets are about 1 cm apart. The flowers are greenish-white to yellow, abundant and occur in spike-like racemes. The pods are beige to off-white, about 15 cm long and 15 mm wide. The pods have a tendency to be rolled up along the axis. Seeds many, bean-shaped, oblong, 6-7 mm long, flattened, brown, each in 4-angled case

2.8.2. Wood

Its wood is dark brown, frequently with a purple hue; it is very hard and the grain is irregular, but easy to work. It has applications in carpentry, floors, and as poles and fuel (Serena, 1980).

CHAPTER THREE MATERIALS AND METHODS

3.1. Wood

The wood material used in this investigation was obtained from *Prosopis chilensis* (mesquite) collected from Bara area, Northern Kordofan state. The wood manually was cutted into chips, milled using hammermill and then screened using a set of standard meshes. The portion which passed through mesh 0.5 mm was used for wood solubility and that passed through mesh 2 and 4 mm was used for preparation of the test specimens because it constitutes the bulk of the prepared wood material (about 80%).

3.2. Cement

Portland cement produced by Atbra cement Corporation, Sudan was used as binding material for all experiments.

3.3. Equipment and Chemicals

The Chemicals used in this study include:-

- a. Calcium chloride CaCl_2 used as cement setting accelerator.
- b. Sodium hydroxide NaOH used as pretreatment solvent.
- c. Gypsum used as chemical additives.

Instruments used are:-

- a. Sensitive balance.
- b. Metallic mould.
- c. Petri dishes, magnetic stirrer, universal drying oven, water bath, conical flasks and beakers.

3.4. Methods

3.4.1 General

The experimental part of this study consisted of four main experiments; some of the promising results obtained in the first three experiments will be used in latter one. These experiments are:-

- a. Determination of extractive content of mesquite wood (extractives solubility) using cold water, hot water and mild alkali extraction methods following ASTM standard, 1981.
- b. Selection of the best pretreatment/s to be applied to mesquite wood to improve its compatibility with ordinary Portland cement (Soaking in water, soaking in sodium hydroxide solution, addition of calcium chloride and addition of gypsum).
- c. Investigation of the effect of cement/wood ratios (2:1, 3:1, 4:1 and 5:1) on the properties of mesquite wood cement aggregates.
- d. Studying the effect of cement partial replacement by gypsum when low cement wood ratio (3:1) was used.

3.4.2 The effect of Extraction methods on mesquite wood extractive content

The experiment was conducted in Completely Randomized Design (CRD) under laboratory environment with three replicates for both sapwood and heartwood. Following the ASTM standard, 1981 the solubility of mesquite extractives or extractive content was studied using the following methods:-

1. Soaking in Cold water.
2. Soaking in Hot water.
3. Using two concentrations of Sodium hydroxide solutions (0.5% and 1%).

3.4.2.1 Cold water extraction

Two grams of milled oven dry wood were soaked into 300 ml of distilled water and left for 48 hours at room temperature, the soluble portion was filtered, collected and its pH determined. Then the residues were washed with distilled water and dried into an oven at 105°C, then weighed and drying process was continued until constant weight was obtained, then the extractive content was calculated.

3.4.2.2 Hot water extraction

For hot water extraction, ASTM (1981a) was followed. Two grams of (oven dry) milled sieved wood were soaked into 100 ml of hot distilled water and maintained at 70°C in water bath for three hours, then the sample was treated as in cold water extraction, pH of extract was determined and residue was oven dried and weighed.

3.4.2.3 Mild alkali extractions

Two concentrations of Sodium hydroxide solution were prepared, (namely 0.5% and 1%) and used as extraction agent. According to ASTM (1981b) two grams of milled sieved wood were soaked in 100 ml of 0.5% sodium hydroxide solution and maintained in a water bath at 97-100°C for one hour, then the soluble portion was collected and pH was determined. The residue was washed with 50 ml of 10% acetic acid and then washed thoroughly with hot distilled water and oven dried until constant weight was obtained. The same procedure was followed for 1% sodium hydroxide extraction.

3.4.3 Effect of pretreatments applied to mesquite wood

For this experiment the wood particle portion used was that which passed through mesh 2 and 4 mm. The pretreatments used for

mesquite wood to improve its compatibility with Portland cement were:-

1. Soaking in cold water.
2. Addition of calcium chloride
3. Soaking in 1% sodium hydroxide
4. Addition of gypsum

3.4.3.2 Methods

Soaking in cold water

For cold water treatment wood particles were soaked in tap water for two weeks. Every two days water was replaced by clean water to remove water soluble extractive that dissolved, and then the wood particles were air dried for one week. Using a fixed cement wood ratio of 2:1 and the appropriate amount of water, a mixture of wood, cement and water was prepared from which five experimental specimens were produced. The appropriate amount of water was calculated according to the following equation:

$$W = 0.35C + (0.3 - MC) \times W_o$$

Where

W: water/L

C: Cement weighs Kg

W_o: Oven dry weigh of wood Kg

MC: Moisture content of wood

The specimens were prepared using metallic mould of 7×7×7cm. Then the specimens were left for 24 hours for cement setting, and the metallic mould was removed from the specimens after which the specimens were soaked in water for 28 days in order to allow complete curing of cement.

Soaking in sodium hydroxide solution

Sodium hydroxide solution was used as a treating agent. The wood particles were soaked in 1% sodium hydroxide solution for 24 hours, and then the particles were washed several times with tap water to remove the sodium hydroxide and extractive. They were left to air dry after that five specimens were prepared using the same method described in the previous section.

Addition of Calcium chloride (CaCl₂)

Based on cement weight 3% of Calcium chloride was added to the wood, cement and water mixture. Five specimens were prepared from this mixture in the same way as in the preceding sections.

Addition of Gypsum

Based on cement weight 20% of commercial gypsum was added to the mesquite wood cement mixture and then the experiment proceeded as in the cold water treatment to produce five experimental units.

Control

Untreated wood from *Prosopis chillensis* (mesquite) was mixed with cement using the same ratio as control to compare the above mentioned pretreatments. Five specimens were produced using the same method as that used for cold water treatment.

3.4.4 The effect of cement/wood ratios on the properties of mesquite wood cement aggregates

3.4.4.1 Materials

In this experiment the wood particle portion used was that which passed through mesh 2 and 4mm. Ordinary Portland cement manufactured by Atbra Cement Corporation, Sudan was used as

binding material.

3.4.4.2 Methods

The experiment was conducted under laboratory environment using Completely Randomized Design (CRD) with five replicates. Four cement wood ratios namely 2:1, 3:1, 4:1 and 5:1 were used. Wood particles were mixed with Portland cement without any treatment or additives, the required amount of water (according to Basheir 2005) was added, then the mixture was molded into testing metallic mold of (7×7×7 cm) and left for 24 hours for setting. Then the resulting cubes were soaked in water for four weeks for complete cement curing. Thereafter, all the specimens were tested for water absorption for 2 and 24 hour, density and compressive strength.

3.4.5. The effect of cement partial replacement by gypsum on the properties of Mesquite wood cement aggregates

3.4.5.1. Methods

Under completely randomized design with five replicates using a fixed cement wood ratio of 3:1, four levels of cement replacement by gypsum were done. The selected levels of replacement were 10, 20, 30 and 50% based on cement weight. Wood particles were mixed with Portland cement, and the gypsum according to each level of replacement, and then required amount of water (according to Basheir 2005) was added. The mixture was molded into testing metallic mold of (7×7×7cm) and left for 24 hours for consolidation and primary curing of cement. Then the experiment proceeded as in the effect of cement wood ratio. Another replicate was molded

without any gypsum to serve as control.

3.5. Property measurement

3.5.1. Determination of density

Density (g/cm^3) for each specimen ($7\times 7\times 7\text{cm}$) was calculated by dividing weight (air dry weight) by volume of the specimen.

3.5.2. Determination of water absorption

Based on the initial air dry weight of the specimens, percentage of water absorption was calculated after soaking in water for 2 and 24 hours by direct weighing of specimens after soaking time.

3.5.3. Determination of compressive strength

The specimens prepared in each of the above-mentioned experiments were tested for compressive strength using a universal testing machine. The compressive strength was calculated by dividing the maximum load over the cross sectional area of the cube sample. Maximum load in kilogram was recorded and compressive strength (kg/cm^2) was worked out.

3.5.4. Statistical Analysis

The data collected from the above mentioned experiments was analyzed using (SAS) software 1996. Analysis of variance and mean separation test using duncan multiple range test.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Effect of extraction methods

The crucial problems of wood that retard the development of wood cement bonded product is the presence of wood extractives that contain poisoning substances which delay cement stiffness and cause inhibition of cement hardening and curing.

Table 1 shows the result of the mean separation test for the effect of different extraction methods used to determine the extractives content of mesquite wood.

There was significant difference between the extraction methods ($P=0.005$, ANOVA Appendix Table 1). One percent mild alkali extraction method gave the highest content and was significantly different from cold and hot water extraction methods, while no significant differences was observed between 1 and 0.5% mild alkali extraction method. Also no significant differences was found between 0.5% mild alkali extraction and cold water method, which was not significantly different from hot water extraction. Generally as the severity of extraction method increase the percentage of extractive content increased. These conclusion not agreed with the findings of Mohammed (1999) when he concluded that, the extractive contents of the studied species (*Acacia nilotica*, *Calotropis Procera*, *Cupressus lusitanica* and *Eucalyptus microtheca*) varied between 5.9% and 11.2% when extracted with cold water, between 19.5% and 25.65 when extracted with hot water and between 23% and 39.6% when extracted

with NaOH 1% and increased by increasing the severity of extraction method. These results indicated that mesquite wood extractive can successfully be removed or minimized by soaking in cold water. Gnanaharan and Dhamodaran, (1985) examined the effect of water extraction on the solubility of 13 tropical hardwood extractives for wood-wool-cement-board manufacturing. They found that extraction with cold water was sufficient to remove the inhibitory extractives from most of the tested species.

Table.1. The effect of extraction methods on mesquite wood extractive content

Extraction method	Extractive content (%)
NaOH 1%	31.07a
NaOH 0.5%	28.60ab
Cold water	20.19bc
Hot water	12.60c

In the same column, means with the same letter/s are not significantly different at $P=0.05$

4.2. Effect of wood types on extractive content

Table 2 shows the data obtained from the cold water extraction

method, there was no significant differences was between the extractive content of sapwood and heartwood of mesquite. This result indicated that there is no need to separate sapwood and heartwood. They can be used for cement bonded products as derived from the logs or the trees.

Table.2. The effect of wood types on the extractive content (cold water extraction)

Wood type	Extractive content (%)
Heartwood	23.52a
Sapwood	22.72a

Means with the same letter/s are not significantly different at $P = 0.05$

4.3. Effect of wood pretreatment on the density of mesquite wood

cement bonded aggregates

Appendix Table 4 shows the ANOVA results of the air dry density, which showed highly significant differences between the pretreatments was observed ($P=0.0001$).

The results of the mean separation test for the effect of wood pretreatment on the air dry density of the mesquite wood cement bonded aggregate is presented in Table 3. Significant difference was found between addition of gypsum and other pretreatments, the addition of gypsum rank first, while no differences were observed between addition of calcium chloride and untreated wood (control) which were significantly different from either soaking in cold water or 1% sodium hydroxide solution. As expected, addition of gypsum increases the air dry density and this obviously due to high density of gypsum itself. Also this finding was not in lined with the finding of Ahn and Moslemi (1980) who observed that CaCl_2 tends to improve the bond between wood and cement and rank first, while in this study addition of calcium chloride ranks second and share the same ranks with untreated wood. Such an improvement in bonding might be accountable for the observed increase in air dry density. From all above discussed results it can be concluded that mesquite wood can combine well with cement even without treatment.

Table.3. Effect of wood pretreatments on the air density of mesquite wood cement bonded aggregate (g/cm³)

Treatments	Means
Gypsum	1.126 a
Calcium chloride	1.009 b
Control	0.9972 b
Cold water	0.9176 c
NaOH 1%	0.8338 d

In the same columns, means with the same letter/s were not significantly different at 0.05

4.4. The effect of wood pretreatments on compressive strength

The results of the mean separation test for the effect of different wood pretreatments on compressive strength (Kg/cm^2) were presented in Table 4. The analysis of variance showed that there were significant differences between the pretreatment ($P = 0.0001$, Appendix Table 5). As shown in Table 4 addition of gypsum gave the highest value and was significantly different from all other treatments followed by control, addition of calcium chloride and soaking in cold water, between which no differences were found. Extraction by NaOH 1% was ranked last, and this may be attributed to the adverse effect of the sodium in lowering the air dry density, in this study increasing density associated with better properties and this is goes in total agreement with the finding of Ibrahim (1995) who stated that the compressive strength is highly correlated with the density of wood cement mixture. Previous works of Hassan (1999) and Ibrahim (1995) concluded that, addition of calcium Chloride help in improving the compressive strength and ranked first, while in this study addition of calcium chloride ranked secondly. Addition of gypsum (20% -based on cement weight) increased the compressive strengthly more than 100% compared with the others treatments and displaced calcium chloride from the top rank. This may possibly be due to increased air dry density. An exciting result was that soaking mesquite wood in cold water as well as control shared the same rank with addition of calcium chloride, which indicated that mesquite wood can safely be used to produce cement bonded products without any sort of treatment. This may be attributed to the fact that the extractives

present in mesquite wood did not have an inhibitory effect on cement setting.

Table.4. Effect of wood pretreatment on the compressive strength of mesquite wood/cement bonded aggregates

Treatment	Compressive strength (kg/cm ²)
Gypsum	51.318 a
Control	24.799 b
Calcium chloride	24.675 b
Cold water	23.223 b
NaOH 1%	09.123 c

Means with the same letter/s are not significantly different at $P = 0.05$

4.5. Effect of wood pretreatments on water absorption percentage of mesquite wood – cement aggregates.

Appendix Table 2 shows the analysis of variance for the pretreatments

and showed highly significant differences between pretreatments ($P=.0001$). Table 5 shows the results of the mean separation test for the effect of wood pretreatment on the water absorption percentage of mesquite wood – cement bonded aggregates. When soaked for two hours, addition of gypsum, addition of calcium chloride and controls gave the best result and were not significantly different from each other, but were significantly different from soaking in cold water and soaking in 1% sodium hydroxide solution (Table 5). But when soaking was extended to 24 hours, addition of gypsum and addition of calcium chloride significantly improved water absorption, while control ranked third, but not significantly different from addition of calcium chloride. Soaking in 1% sodium hydroxide solution showed the highest percentage of water absorption. Generally pretreating any hardwood improves water absorption percentage due to improvement of cement setting conditions. Previous work by Hassan (1999) and Abdalla (1998) concluded that the addition of calcium chloride significantly improved water absorption percentage. However addition of gypsum in this study showed better board performance than addition of calcium chloride in improving mesquite wood cement bonded aggregate.

Table.5. Effect of wood pretreatments on water absorption of mesquite wood –cement bonded aggregates

Wood pretreatments	Water absorption percentage	
	2 hours soaking	24 hours soaking
NaOH 1%	45.423 a	50.286 a
Cold water	32.491 b	37.582 b
Control	24.688 c	28.126 c
Calcium chloride	22.708 c	26.489 cd
Gypsum	18.796 c	22.736 d

In the same columns, means with the same letter/s were not significantly different at $P= 0.05$

4.6. Effect of cement/wood ratios on the density of mesquite wood/cement bonded aggregates

Appendix Table 4 shows the analysis of variance results for the effect of cement wood ratio on the properties of mesquite wood cement

aggregates, highly significant differences between the different ratios (P=.0001). The results for the effect of cement wood ratio on mesquite wood-cement bonded aggregates air dry density were presented in Table 6. The mean separation test shows that, no significant differences were observed between ratios 4:1 and 5:1 which gave the highest value. But there were significant differences between the other ratios. As expected increasing cement/wood ratio results in increased aggregate air dry density since addition of more cement means increasing the specimen weight. The same conclusion was found by Zhou and Kamdem, 2002 who stated that, cement-bonded particleboard that utilize large amounts of cement in comparison to wood (cement: wood ratio higher than 3:1), result in final product with high density (>1300 kg/m³), because cement is denser than wood. Also Oyagade *et al.*, (1995) reported that veneer laminated cement-bonded particleboard were stronger and stiffer with increased cement/wood ratio due to increased density. Also Lee (1984) stated that if a lower cement/wood ratio is used, wood excelsior will not receive adequate cement coating, which results in poor bonding.

Table.6. Effect of cement/wood ratios on the density of mesquite wood/cement bonded aggregates

Cement /wood ratio	Density (g/cm ³)
5:1	1.475 a

4:1	1.394 a
3:1	1.148 b
2:1	0.822 c

In the same columns, means with the same letter/s were not significantly different at $P= 0.05$

4.7. Effect of cement /wood ratios on compressive strength of mesquite wood-cement bonded aggregates.

The results of mean separation test for the effect of cement/wood ratio on mesquite wood-cement bonded aggregates compressive strength were shown in Table 7. Significant differences were found between the four studied ratios. As observed from the Table 7 increasing cement: wood ratio resulted in increasing compressive strength. This can be attributed to the increased air dry density. This goes in total agreement with the finding of Abdelgadir and Ibrahim (2003) who concluded that compressive strength of cement- wood mixture for five Sudanese hardwood species is considerably reduced as cement/wood ratios were decreased and the opposite was true.

Table.7. Effect of cement/wood ratios on the compressive strength of mesquite wood/cement bonded aggregates

Cement/wood ratios	Compressive strength (Kg/cm ²)
5:1	110.72 a
4:1	90.90 b
3:1	37.94 c
2:1	16.59 d

In the same columns, means with the same letter/s were not significantly different at $P = 0.05$.

4.8. Effect of cement/ wood ratio on the water absorption of mesquite wood-cement bonded aggregates

Appendix Table 2 shows the analysis of variance results for the effect of cement wood ratio on the water absorption percentage of mesquite wood cement aggregates with highly significant differences between the different ratios ($P=.0001$). The results of mean separation test for the effect of cement/ wood ratio on water absorption are shown in Table 8. When the specimens were soaked for 2 hours, significant differences between the ratios were observed, with the trend that as cement wood ratio increased water absorption decreased. This result goes in total agreement with the finding of Eusebio, *et al.* (1998) who found that the water absorption tended to decrease as the amount of cement was increased from 50:50 to 30:70. Obviously, a higher wood content (lower cement: wood: ratio), would result in greater water absorption due the nature of wood which will be less surrounded by cement, but increasing the cement ratio results in better coating of wood particles. This prevents them from absorbing water. There were also significant differences between ratios when specimens were soaked for 24 hours, which indicate that the aggregates absorbed huge amount of water during the first hours of soaking, while increasing the soaking time result in only a few percentages of increase (3-6%), which agreed well with the conclusion of Hassan, (1999) who concluded that soaking in water for 24 hours increased the mount of water absorption by an average of 6% compared to soaking for 2 hours. From all above mentioned results, it may be concluded that aggregates with low cement wood ratio absorb more water and possesses lower compressive strength. However, aggregates with higher cement/wood ratio (4:1 and 5:1) absorb small amount of water,

possesses higher compressive strength and heavy weight (high density). The aggregate produced with cement wood ratio of 3:1 had reasonable weight, good strength and reliable density. The overall conclusion is that 3:1 cement wood ratio is the suitable and recommended ratio to be used for untreated mesquite wood.

Table.8. Effect of cement/wood ratio on the water absorption of mesquite wood–cement bonded aggregates

cement/wood ratio	Water absorption percentage	
	2 hours soaking	24 hours soaking
2:1	44.66 a	50.8 a
3:1	31.55 b	34.9 b
4:1	23.64 c	27.9 c
5:1	19.38 d	25.9 c

In the same columns, means with the same letter/s were not significantly different at $P = 0.05$

4.9. Effect of cement partial substitute by gypsum on the air density of mesquite wood/cement bonded aggregates

Appendix Table 4 shows the analysis of variance results for the effect of cement partial substitute with gypsum on the air dry density of mesquite wood cement aggregates, highly significant differences between the different ratios ($P=.0001$). The results of the mean separation test for the effect of cement partial replacement by gypsum on mesquite wood-cement bonded aggregates air dry density were presented in Table 9. The mean separation test shows that, no significant differences were found between the different percentages of the substitute (10, 20, 30 and 50%, based on cement weight). But there is a trend of reducing density by increasing the gypsum replacement percentage and statistically appear to be significant. In general the pure cement density is approximately twice the density of the gypsum ([www. en.wikipedia.org](http://www.en.wikipedia.org), 2008). This fact may explain the reduction caused in specimens air dry density as gypsum replacement percentage increase.

Table.9. Effect of cement partial substitute by gypsum on the density

of mesquite wood/cement bonded aggregates

Gypsum percentage	Density (g/cm ³)
Control (0)	1.148 a
10	1.097 b
20	1.057 b
30	1.034 b
50	1.014 b

In the same columns, means with the same letter/s were not significantly different at $P = 0.05$

4.10. Effect of cement partial substitute by gypsum on the compressive strength of mesquite wood-cement bonded aggregates

The results of mean separation test for the effect of cement partial substitute by gypsum on mesquite wood-cement bonded aggregates compressive strength were shown in Table 10. Significant differences were found between replacement percentage of 10, 20, 30 and 50%. The highest compressive strength was associated with 10% substitute which was significant differences from all other substitute levels. This was followed by 20%. However no significant differences were observed between 30 and 50% substitute. When comparing this result with control, the control compressive strength showed no significant difference from that of 20% replacement, while 10% replacement improved the compressive strength significantly over that of the control. The gypsum partial replacement of 10% increased the compressive strength more than 100 percent when compared with the percentage 30 and 50. This indicated that the partial replacement of cement by gypsum in fewer amount is sufficient to improve the aggregates compressive strength. While increasing the percentage more than 20% causes reduction on compressive strength of the aggregate. This may be attributed to the fact that increasing the amount of gypsum affected the setting and curing process of cement through absorbing more water, rendering insufficient amount of water for cement setting. Also a possible explanation may be due to the reduction which occurred in the aggregate density. According to Sudanese Standard (1974), the minimum requirement of compressive strength for burnt clay bricks, should not be less than 20 Kg/cm².

Referring to the result of this experiment, the worst mesquite wood cement aggregates showed compressive strength of 24.8 Kg/cm² which exceeds the required compressive strength by the standard.

Table.10. Effect of cement partial substitute by gypsum on the compressive strength of mesquite wood/cement bonded aggregate

Percentage of gypsum replacement (%)	Compressive strength (Kg/cm ²)
10	56.89 a
20	39.37 b
Control	37.94 b
30	25.74 c
50	24.88 c

In the same columns, means with the same letter/s were not significantly different at $P=0.05$.

4.11. Effect of cement partial substitute by gypsum on water absorption of mesquite wood-cement bonded aggregates

The results of mean separation test for the effect of cement partial replacement by gypsum on water absorption of mesquite wood cement bonded aggregate are shown in Table 12. Lower percentages

of substitute significantly improve water absorption of the aggregate when soaked for both 2 and 24 hours. Increasing replacement percentage significantly increases water absorption for both periods of soaking. A possible explanation may be that increasing gypsum percentage takes more water during the molding, so negatively affect the process of cement setting. Which result in poor coating of wood particles with cement, so when subjected to moisture, they absorbed large quantity of water.

Table.11. Effect of cement partial substitute by gypsum on water absorption of mesquite wood–cement bonded aggregate

Gypsum replacement percentage (%)	Water absorption percentage	
	2 hours soaking	24 hours soaking

50	34.06 a	36.94 a
30	33.90 a	37.76 a
Control	31.55 a	34.90 a
20	30.85 ab	33.84 ab
10	26.45 b	29.85 b

In the same columns, means with the same letter/s were not significantly different at $P= 0.05$

Summary

Density

-In the pretreatments significant difference was found between addition of gypsum and other pretreatments, the addition of gypsum rank first, while no differences were observed between addition of calcium chloride and untreated wood (control) which were significantly different from either soaking in cold water or 1% sodium hydroxide solution. As expected, addition of gypsum increases the air dry density and this obviously due to high density of gypsum itself.

-The mean separation test shows that, no significant differences were observed between ratios 4:1 and 5:1 which gave the highest value. But there were significant differences between the other ratios. As expected increasing cement/wood ratio results in increased aggregate air dry density since addition of more cement means increasing the specimen weight.

-The results of the mean separation test for the effect of cement partial replacement by gypsum on mesquite wood-cement bonded aggregates air dry density, the mean separation test shows that, no significant differences were found between the different percentages of the substitute (10, 20, 30 and 50%, based on cement weight). But there is a trend of reducing density by increasing the gypsum replacement percentage and statistically appear to be significant.

Compressive strength

-The results of the mean separation test for the effect of different

wood pretreatments on compressive strength (Kg/cm^2), the addition of gypsum gave the highest value and was significantly different from all other treatments followed by control, addition of calcium chloride and soaking in cold water, between which no differences were found. Extraction by NaOH 1% was ranked last, and this may be attributed to the adverse effect of the sodium in lowering the air dry density, in this study increasing density associated with better properties.

-The results of mean separation test for the effect of cement/wood ratio on mesquite wood-cement bonded aggregates compressive strength, significant differences were found between the four studied ratios, increasing cement: wood ratio resulted in increasing compressive strength. This can be attributed to the increased air dry density.

-The results of mean separation test for the effect of cement partial substitute by gypsum on mesquite wood-cement bonded aggregates compressive strength, significant differences were found between replacement percentage of 10, 20, 30 and 50%. The highest compressive strength was associated with 10% substitute which was significant differences from all other substitute levels. This was followed by 20%. However no significant differences were observed between 30 and 50% substitute. When comparing this result with control, the control compressive strength showed no significant difference from that of 20% replacement, while 10% replacement improved the compressive strength significantly over that of the control. The gypsum partial replacement of 10% increased the compressive strength more than 100 percent when compared with the

percentage 30 and 50.

Water absorption for 2 and 24 hours

-The results of the mean separation test for the effect of wood pretreatment on the water absorption percentage of mesquite wood – cement bonded aggregates. When soaked for two hours, addition of gypsum, addition of calcium chloride and controls gave the best result and were not significantly different from each other, but were significantly different from soaking in cold water and soaking in 1% sodium hydroxide solution .But when soaking was extended to 24 hours, addition of gypsum and addition of calcium chloride significantly improved water absorption, while control ranked third, but not significantly different from addition of calcium chloride. Soaking in 1% sodium hydroxide solution showed the highest percentage of water absorption. Generally pretreating any hardwood improves water absorption percentage due to improvement of cement setting conditions.

-The results for the effect of cement wood ratio on the water absorption percentage of mesquite wood cement aggregates with highly significant differences between the different ratios ($P=.0001$). The results of mean separation test for the effect of cement/ wood ratio on water absorption, when the specimens were soaked for 2 hours, significant differences between the ratios were observed, with the trend that as cement wood ratio increased water absorption decreased. There were also significant differences between ratios when specimens were soaked for 24 hours, which indicate that the aggregates absorbed huge amount of water during the first hours of

soaking, while increasing the soaking time result in only a few percentages of increase (3-6%).

-The results of mean separation test for the effect of cement partial replacement by gypsum on water absorption of mesquite wood cement bonded aggregate the Lower percentages of substitute significantly improve water absorption of the aggregate when soaked for both 2 and 24 hours. Increasing replacement percentage significantly increases water absorption for both periods of soaking.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:

Based on the findings and results of this study, the following conclusions can be drawn:-

- Mesquite (*Prosopis chilensis*) wood extractives can successfully be removed or minimized by soaking in cold water.
- There is no need to separate sapwood and heartwood. They can be used for cement bonded products as derived from the logs or the trees.
- Mesquite wood can combine well with cement even without treatment.
- Addition of gypsum (20% based on cement weight) increased the compressive strength more than 100% when compared with the other treatments.
- The addition of gypsum resulted in better performance than the addition of Calcium chloride.
- Increasing cement portion resulted in increased aggregates density.
- Aggregates with low cement wood ratio absorbed more water and gave lower compressive strength, while, aggregates with higher cement content absorbed small amount of water resulting in higher compressive strength and heavy weight (high density). Aggregates produced with cement wood ratio of (3:1) had reasonable weight, good strength and reliable density.
- The gypsum partial substitute of 10% increased the compressive strength more than hundred percent when compared with the percentage 30 and 50, this expressed that the partial substitute of cement by gypsum in fewer amount is sufficient to improve the aggregates compressive strength.

5.2 Recommendations

- More study is needed to investigate the use mesquite (*Prosopis chilensis*) wood without any treatments for producing cement wood aggregates, also it is recommended to use the all parts of the tree e.g. wood with bark, twigs, spineetc.
- Additional research is needed to understand the behavior of wood cement aggregates of *Prosopis chilensis* and

improve the compatibility between the wood and cement with many other treatments and additives.

- Research is needed to find a suitable equation to calculate water requirement to be added to wood-cement mixture when gypsum is used to substitute the cement.
- More work is needed to investigate the problems of settings between gypsum and cement.

REFERNCES

- Abdalla, A.M. 1998. Effect of Pretreatment, Particle size, pressure and cement/wood ratio on the properties of cement-bonded products from *Acacia nilotica* (sunt) wood. *M.Sc. thesis submitted to the University Khartoum*.
- Abdelgadir, A.Y, and M.F.S Ibrahim 2002. A note on the compatibility of five home-grown species with Portland cement. *University of Khartoum Journal of Agriculture Sciences* 10 (1): 150-155.
- Abdelgadir, A.Y. and M.F.S. Ibrahim 2003. Effect of pretreatments and cement/wood ratio on compatibility of wood with Portland cement. *Sudan Silva* 9(2): 77-85.
- Ahn, W. Y.; Moslemi,A.A. 1980. SEM examination of Portland cement bonds. *Wood Sciences and Technology*. 13: 17-82.
- Alberto, M.M; E. Mougel and A. Zoulalian 2000. Compatibility of some tropical hardwood species with Portland cement using isothermal calorimetry. *Forest product Journal*. 50(9): 83-88.
- American Society of Testing and Materials (ASTM). Annual Book of ASTM Standards, Vol. 04-02. C39-83b.
- Anonymous 2001. Manufacturing processes of wood-cement panels.<http://www.anu.edu.au/Forestry/wood/cfb/manuf.html>.12/06/02. (Accessed in 2007).
- Badejo, S.O.O. 1988. Effect of Flake geometry on properties of cement bonded particleboard from mixed tropical

- hardwood. *Wood Science and Technology* 22(4): 357-3370.
- Bash, S.M. and SH.M. Rakhimbaev. 1973. Influence of additives on setting of plugging cement. T: cement 11:16-17. (Chemical Abstracts 80:9953r).
- Basher, A.B.A. 2005. Effect of some technological factors on some properties of *Acacia seyal* (Talh) wood-cement aggregates. *M.Sc. Thesis Submitted to the University of Khartoum*.
- Bensted, J. 1987. Some application of conduction calorimetry to cement hydration. *Advances in Cement Research*. 1(1):35-44.
- Bentur, A. and Mindess, S. 1990. Fibre Reinforced Cementitious Composites Elsevier Science Publishers Limited, Essex, England 449 pp.
- Bhatty, J.I. 1991. A review of the application of thermal analysis to cement-admixture systems. *Thermochimica Acta* 189:313-350.
- Biblis E.G. and C.F. Lo. 1968. Sugars and other wood extractives effect on the setting of southern pine –cement mixture. *Forest product. Journal*. 18(8) 313-350.
- Blankehorn, P.R. 1994. Compressive strength of hardwood-cement composite, *Forest Product Journal*. Vol. 44, No. 4, Pp.59-62.
- Browning, B.L.1967. *Methods of Wood Chemistry* Vol. 1. Inter science publisher. New York. pp. 384.
- Chen, T.Y.; S.R. Hwang, and C.Y.Hse. 1998. Effect of wood species on the properties of cement-bonded wood particleboard. Adhesive Tech. and Bonded Wood Prod. TFRI Extension Series 96:554-564. *Conference*, SP 179, Tokushima, Japan

Pp. 905-928.

Dinwoodie, J. H. 1991. The long term performance of cement-bonded wood particleboard. In: Proceeding. Inorganic bonded wood and fiber composite materials. Forest Product Society, Madison, Wis. Pp.45-54.

Dinwoodie, J. M.; Paxon, B. M. 1983: wood cement particleboard- A technical assessment. *Building Research Establishment information paper. IP 4/83:14.*

El Tayeb, A., Mahir, M.A. and El Hassan (2001) Mesquite present status and challenge. A report on mesquite in New Halfa Agricultural Scheme. pp. 37

Elten, G.V. 2000. Production, Properties and application of various woods cement products. *Especially wood Journal. September/October 2000:18-24.*

Farmer, R.H. 1967. The Utilization of Wood. In: Mohamed. T. E. 2004. Effect of mixing some wood and Non-wood lignocellulosics materials on the properties of cement and Resin-Bonded particleboard. *PhD. Thesis submitted to the University of Khartoum.*

Fischer, U.F.; O. Weinhaus; M. Ryssel, and J. OLBrecht 1974. Water soluble Carbohydrate in wood and their influence on the manufacture of wood wool light building slabs, *Holztechnogic 15 (1):9-12.*

Gnannaharan, R, and T. K. Dhamodaran, 1985. Suitability of some tropical hard wood for cement-bonded wood-wool board

manufactures *Holzforschung* 39(6):337-340.

Goldstein. I.S.1984. Degradation of wood by chemicals. Chapter 15 in R.Rowell, Ed. The chemistry of Solid wood. Am. Soci. Advances in chemistry services. No.207. American Chemical Society, Washington, Dc.

Gong.An; Kamdem, D.P., and Harichandran, R. 1993. Compression tests on wood-cement particle composite made of CCA-treated wood removed from services. Department of Civil and Environmental Engineering, 3546 Building, Michigan State University, East lansing, M148824.

Hachemi, M. and A.G. Campell. 1990. A new technique to classify the compatibility of wood cement. *Wood Science. Technology.* 24(4):345-354.

Hachemi. M. and A.A. Moslemi. 1989. Correlation between wood-cement compatibility and wood extractives. *Forest Product Journal.* 39(6):55-58.

Hassan, T.T.E. 1999. Effect of Some Physical and Chemical additives on the mechanical and physical properties of Acacia nilotica wood cement mixture. *M.Sc. Thesis submitted to the University of Khartoum.*

Hofstrand, A. D.; A.A. Moslemi and D.F. Garcia 1984. Curing characteristics of wood particles from nine Rocky Mountains species mixed with Portland cement. *Forest Product Journal* 34 (2): 57-61.

Ibrahim. M. F. 1995. Effect of Species Treatment and Cement wood Ratios on the Compressive Strength of Wood-Cement

Mixture. *M.Sc. Thesis, Faculty of Forestry, University of Khartoum-Sudan.*

Jain, V.K.; Shukla, K.S.; Kumar, S. and Satish K. 1989. Heat of hydration Studies on cellulosic materials and cement systems. *Journal Timber Development association* 32 (2) 19-32.

John. A. 1999. Wood based composite and panel products. Forest products laboratory, wood handbook; Wood as an engineering material. Gen. Tech. Rep FPL-GTR-113 Madison.

Kammall. R.N. and K. Suwandi 1974. Test on eight wood species from lampung (S. Sumatral) and Jasinga, for wood-wool board. Lapran, Lembaga penelitia, Hufan No.33. (Cited from Forest abstracts-1975.36:4233).

Kasai, Y.; Kawamura, M. and Zhou, J.D., 1998. Study on Wood Chip Concrete with Timber. In: V.M. Malhotra (Ed.). *Recent Advances in Concrete Technology: Proceedings: 4th CANMET/ACI/JCI International Conference*, SP 179, Tokushima, Japan, Pp. 905-928.

Kumar, S. 1980. Development of wood-wool boards from indigenous materials. P1-480 Project. Final Research report, Forest Research institute and College, Dehra dun, India.96, Pp (As cited by Jain, V.K.; Shukla, K.S.; Kumar, S. and Satish K. 1989. Heat of hydration Studies on cellulosic materials and cement systems. *Journal Timber Development association* 32 (2) 19-32).

Lea, A.W.C. 1965. The chemistry of cement and concrete (As cited

- by Moslemi, A.A 1974. particleboard. Volume I and II (*Materials and Technology*) Southern Illionis University press, Carbondale 111.P185-186.
- Lee, A. W. C. and Z. Hong 1986. Compressive strength of cylindrical samples as an indicator of wood-cement compatibility. In: *Forest Product Journal* 36 (11/12):87-90.
- Lee, A. W.C. 1984. Physical and mechanical properties of cement-bonded southern pine excelsior board. *Forest Products Journal* 34(34): 30-34.
- Liu, Z., and A.A. Moslemi 1986. Effect of western Larch extractives on cement-wood setting. *Forest product Journal* 35(7/8): 37-43.
- Malloney, T. M. 1989. Composition Board Materials: properties and testing of Modern Particleboard and dry process fiberboard, Manufacturing Pp: 40-43: 120-128.
- Manzanares, K.; D. Velazouez, and O. Mareinez 1989. Suitability of three forest species for manufacture of wood-cement panels. *Revista Forestal Baracoa* 19 (1): 101-107 (Cited from *Forest Products Abstracts*. 1993. 016:00299).
- Mariampolskii, N. A.; A. I. Perkov, and Y.A. Shawachkin. 1974. Mechanism of activities of reagents which retard the setting of plugging cement slurries. *Neft.Khoz.*10:27-30 (As cited by Miller, D.P and A.A. Moslemi 1991b. Wood cement composites: Effect of model compound on hydration characteristics and tensile strength. *Wood and Fiber Sciences* 12(4): 472-482).

- Miller, D. P. 1987: Wood-cement composite: interactions of wood components with Portland cement Ph.D. Dissertation, University of Idaho, and Moscow, Idaho, USA.
- Miller, D.P., and A.A. Moslemi 1991b. Wood-cement composites: II. Effect of model compounds on hydration characteristics and tensile strength. *Wood and Fiber Science*. 23 (4):472-482.
- Miller, P., A.A. Moslemi 1991a. Wood cement composites: I. Effect of model compound on hydration characteristics and tensile strength. *Wood and Fiber Sciences* 12(4): 472-482.
- Ministry of Industry-Sudan 1974. Sudanese Standard for Common Burnt –clay Building Bricks. Department of Standardizations and Quality control. Ministry of Industry-Sudan, September 1974.
- Mohammed, A.A 1999. The effect of wood extractives of some Sudanese tree species on Portland cement setting.
M.Sc thesis submitted to the University Khartoum.
- Moslemi, A.A 1974. Particleboard. Volume I and II (Materials and Technology) Southern Illinois University press, Carbondale 111.P185-186.
- Moslemi, A.A. and Pfister, S.C. 1987. The influence of cement/wood ratio and cement type on bending strength and dimensional stability of wood–cement composite panels. *Wood & Fiber Science*, 19, 165–175.
- Moslemi, A.A. and Y. T. Lim. 1984. Compatibility of southern hardwoods with Portland cement. *Forest product Journal*. 34 (7/8):22-26.
- Moslemi. A.A. 1974b Particleboard. Volume 11 Technology

Southern Illionis University Press.

- Moursi, M. I. 2002. Utilization of Farm Solid Waste in Building materials. M.Sc. Thesis, Faculty of Agriculture, University of Alexandria, Egypt.
- Nasser, R. A. A. 1996. Compatibility of some wood species with Portland cement and its enhancement using various treatments and chemical additives. M.Sc. thesis, Faculty of Agriculture, Alexandria University- Egypt.
- Olorunnisola A.O. and O.O. Adefisan, 2002. Trial production and testing of cement-bonded particleboard from rattan furniture waste. *Wood & Fiber Science*. 34(1):116-124.
- Olorunnisola A.O. Pitman, A. and Mansfield-William, H. 2005a. Strength Properties and Potential Uses of Rattan-Cement Composites. *Journal of Bamboo & Rattan* 4(4): 343-352.
- Oyagade, A.O. 1994. Compatibility of some hardwood with Portland cement. *Journal of tropical Forest Science*. 6 (4):387-396.
- Oyagade, A.O.; S.O.O. Badejo, and O. A. Omole 1995. A preliminary evaluation of flexural properties of wood-veneer laminated cement-bonded particleboard from tropical hardwood species. *Journal of tropical forestry and wood technology of the timber Development association of India* 41 (3): 25-29.
- Paramenwaran, V. N.; Broker, F. W. and Simatupang, M. H. 1977: Micro morphological studies on mineral-bonded wood composite. Interaction between binders and wood. *Holzforchung* 31: 173-178.
- Parameswaran, V. N.; Broker, F. W. 1979; Micro morphological investigation on wood- cement composite after long –term use. *Holzforchung* 33:97-102.

- Pariborto, S., S.Kliwon, and S. Karnasudirdja 1977. Properties of cement bonded boards of five wood species. Forest products research Institute Report No.96.23Pp.
- R.S.P. 1998. Wood Fibre reinforced cement composites from *E. pellita* and *A. mangium* Kraft pulp. *Forest Products Research and Development institute Journal* 24, 57–65.
- Sandermann, H.J. Preusser, and W. Shweers. 1960. The effect of wood extractives on the setting of cement-bonded wood materials. *Holzforschung* 14(3):70-77.
- SAS: Institute Inc.1996/STAT Guide for Personal Computer. SAS institute Inc., Cary, N.C.
- Savuat, N.; R. Sell; E. Mougel., and A. Zoulalian.1999. A study of ordinary Portland cement hydration with wood by isothermal calorimetry. *Holzforchung* 53(1):104-108.
- Semple, K. and P.D. Evans. 1998. Compatibility of some Australian acacias with Portland cement. *Holz Roh-Werkst.* 37:379-382.
- Semple, K. and P.D. Evans. 2000. Adverse effect of heartwood on Properties of wood wool cement boards manufactured from radiat pine wood. *Wood Fiber Science* 32 (1):37-43.
- Serena La. 1980, Morphemical Diversity in *Prosopis chilensis* Population and Evaluation of its growth in plantation at region, National Academy of Sciences. Fire crops, Shrubs and Tree species for energy production. Washington DC.237P. Bernardo Centre, National Forestry Corporation- Chile.
- Simatupang, M.H. 1979. The water requirement of manufactured cement-bonded particleboard. *Holz Roh-Werkst* 37:379-382.
- Stillinger, J. R., and Wentworth, I.W. 1977. Product Process and

Economics of producing Structural Wood-Cement Panels by the Bison-Werke System. In: T.M. Malloney. Proceeding of the Eight Washington State Symposium on Particleboard: 383-410. Washington State University, Pullman, Washington.

Swamy, R.N. 1990. Vegetable Fibre Reinforced Cement Composites – A False Dream or a Potential Reality? In H.S. Sobral (Ed.), Vegetable Plants and their Fibres as Building Materials. Proceedings of the 2nd the Timber Development Association of India, 35, 19–32.

Wadso, L. 2000. The study of cement hydration by isothermal calorimetry. Thermometric. Application Note 314-01. Building Materials, Lund University. Lund, Sweden.

Weather wax, R. C.; Tarkow, H. 1964: Effect of wood on setting of Portland cement. In: Abdalla, A.M. 1998. Effect of Pretreatment, Particle size, pressure and cement/wood ratio on the properties of cement-bonded products from *Acacia nilotica* (sunt) wood. *M.Sc. Thesis submitted to the University Khartoum.*

Whistler, R.L. and J.N. Miller 1958. Alkaline degradation of Polysaccharide. In: Basher, A.B.A.2005. Effect of Some Technological Factors on Some Properties of *Acacia seyal* (Talh) wood-cement Aggregates. *M.Sc. Thesis Submitted to the University of Khartoum.*

Wiki.answers.com/Q/What_is_the_density_of_gypsum_board - 40k. (Accessed 2008).

Wolfe. R. W. 1997: Cement-Bonded Wood Composites as an Engineering Material. Forest Product Society, Madison,

(608) 231-1361, Pp (84-91), <http://www.forestprod.org/>
(Accessed 2007).

Www. en.wikipedia.org, 2008. (Accessed 2008).

Yashiro, Y., Iwase, Y., Seguchi, Y., Takemura, T. and Matsushita, Y.
1992. Manufacture of wood–cement boards V. Cement
hardening inhibitory components of sugi heartwood and
behavior of catechol as a simple Inhibitor model with
vicinal phenolic hydroxyl groups in cement paste. *Mokuzai
Gakkaishi*, 38, 52–58.

Yasin S. M. and T. A. Quershi 1989. Quantity of water soluble in
some hardwood species (A basis for their relative suitability
in wood cement boards). *The Pakistan Journal of Forestry*
39(4):103-106.

Young, J. F.1970. Effect of organic compounds on the interconversion
of calcium aluminate hydrate: Hydration of tricalcium
aluminate. *Journal of American Ceramic Society* 35 (2):
59-65 As cited by Miller, D.P. and A.A. Moslemi. 1991b.
Wood-cement composites: Effect of model compound on
hydration characteristics and tensile strength. *Wood Fiber
Science*. 23(4):472-482.

Young, W.A., and A.A. Moslemi 1984. Korean lignocellulosic and
Portland cement as a structural materials. *Wood Sciences and
Technology, Mogiac Gonghak*. 12 (4):36-46.

Zhengtian. L. and A.A. Moslemi 1986. Effect of Western Larch
extractive on cement setting. *Forest product Journal* 36 (1):53-
54.

Zhou, Y.; Kamdem, D.P. 2002. Effect of cement/wood ratio on the properties of cement-bonded particleboard using CCA-treated wood removed from service. *Forest Products Journal* 52 (2): 73-81.

Appendices

Appendix Table 1. Analysis of variances for extraction methods.

Sources	DF	SS	MS	F-Value	$P \leq 0.05$
Extraction methods	4	0.1279	0.0319	5.25	0.0051
Error	19	0.1157	0.0061		
Total	23	0.2436			

Appendix Table 2. Analysis of variance for water absorption of mesquite wood –cement aggregate for 2 hours

Wood treatment					
Source	DF	SS	MS	F-value	P ≤ 0.05
Treatment	4	2221.13	555.28	28.71	0.0001
Error	20	386.85	19.34		
Total	24	2607.98			
Wood-cement ratio					
Source	DF	SS	MS	F-value	P ≤ 0.05
Ratio	3	1850.93	616.98	88.71	0.0001
Error	16	111.02	6.94		
Total	19	1961.95			
Cement substitute					
Source	DF	SS	MS	F-value	P ≤ 0.05
Percentage	3	190.39	63.47	3.5	0.0454
Error	16	302.92	25.24		
Total	19	493.31			

Appendix Table 3. Analysis of variance for water absorption of mesquite wood –cement aggregate for 24 hours.

Wood treatment					
Source	DF	SS	MS	F-value	P ≤ 0.05
Treatment	4	2456.36	614.09	40.54	0.0001
Error	20	302.93	15.15		
Total	24	2759.29			
Wood-cement ratio					
Source	DF	SS	MS	F-value	P ≤ 0.05
Ratio	3	1982.30	660	72.00	0.0001
Error	16	146.84	9.18		
Total	19	2129.14			
Cement substitute					
Source	DF	SS	MS	F-value	P ≤ 0.05
Percentage	3	193.08	64.36	2.5	0.0923
Error	16	302.92	25.24		
Total	19	596.99			

Appendix Table 4. Analysis of variance for density of mesquite wood–cement aggregate.

Wood treatment					
Source	DF	SS	MS	F-value	P ≤ 0.05
Treatment	4	0.2485	0.0596	19.49	0.0001
Error	20	0.0617	0.0031		
Total	24	0.2996			
Wood-cement ratio					
Source	DF	SS	MS	F-value	P ≤ 0.05
Ratio	3	1.29	0.43	62.65	0.0001
Error	16	0.1098	0.0068		
Total	19	1.40			
Cement substitute					
Source	DF	SS	MS	F-value	P ≤ 0.05
Percentage	3	0.0191	0.0063	1.2	0.411
Error	16	0.1000	0.0063		
Total	19	0.1191			

Appendix Table 5. Analysis of variance for compressive strength of mesquite wood –cement aggregate

Wood treatment					
Source	DF	SS	MS	F-value	P ≤ 0.05
Treatment	4	4038.9	1009.73	10.98	0.0001
Error	20	1748	92.01		
Total	24	5786.90			
Wood-cement ratio					
Source	DF	SS	MS	F-value	P ≤ 0.05
Ratio	3	29167.63	9722.54	91.35	0.0001
Error	16	1702.99	106.44		
Total	19	30870.63			
Cement substitute					
Source	DF	SS	MS	F-value	P ≤ 0.05
Percentage	3	3373.78	1124.59	15.52	0.0001
Error	16	1159.63	72.48		
Total	19	4533.42			