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**Analysis of Fillers for Production of Alternative  
Building Materials Using Magnesia Cement**

**By**

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## **Abbreviations**

<b>CB</b>	<b>Control Board</b>
<b>PS</b>	<b>Pumice Sawdust Board</b>
<b>PC</b>	<b>Pumice Coffee Husk Board</b>
<b>PB1</b>	<b>Pumice Bagasse Board 1</b>
<b>PB2</b>	<b>Pumice Bagasse Board 2</b>
<b>PB3</b>	<b>Pumice Bagasse Board 3</b>
<b>L.I.</b>	<b>Loss of Ignition</b>
<b><sup>0</sup>Be</b>	<b>Degree of Baume</b>

## **Abstract**

Fillers, which are available in the country, are essential for the production of magnesia cement boards. These include pumice and lignocellulostic fillers such as bagasse, sawdust and coffee husk. While applying these fillers to produce the boards, their nature and performance should be studied.

Magnesia cement was used as binding materials; varying boards were produced for different proportion fillers with fixed ratio of magnesium oxide and magnesium chloride.

For the board produced, density, water absorption, and setting time as well as mechanical properties such as the compressive strength and the bending strength determined. In addition, the effects of different fillers on the properties of the board and production cost were examined.

When the saw dust and coffee husk filler substituted the current used bagasse filler, the water absorption and setting time of the boards reduced. While the density, bending strength and compressive strength of the board increased.

The mix ratio of fillers and pumice powder had also influence on the physical and mechanical property of the boards. The test results showed as the proportion of the pumice increased, the mechanical strength of the boards increased and the setting time of the cement paste reduced.

The cost analysis showed that the saw dust board production cost was lower than coffee husk and bagasse board cost. While the production cost of the coffee husk board was slightly higher than others.

In aim of production of filler boards as alternative building materials are, the cost comparison showed in the possibility of producing relatively low price than the hollow concrete blocks included finishing work cost.

# CHAPTER ONE

## Introduction

### 1.1 Background

A wide range of buildings and construction facilities are required by our modern society, including residential and commercial property, manufacturing facilities, schools and hospitals, and a complex transport infrastructure. The construction industry is a major sector of the economy of most nations. The industry is also a very large consumer of minerals and mineral-based materials ranging from aggregates, cement, bricks and tiles to structural steel, glass and ceramics.

A large number of new buildings will need to be built in developing countries during the next generation. All these require massive building programs to create the necessary homes, factories, offices, schools, hospitals and infrastructures. Most of the problems of these countries are related to dependency on factory made building materials such as cement, steel, glass, and etc. Hence, alternative building materials like composites are needed.

Historically, mankind has been familiar with several applications of composite building materials for housing and building needs. Most of these were based on timber, bamboo, jute and a large variety of vegetable fibers such as reinforced mud-blocks for walls, panels for partitioning and roofing.

A composite material has been defined in ASTM D 3878-95c as: A substance consisting of two or more materials, insoluble in one another, which are combined to form a useful engineering material possessing certain properties, not possessed certain properties not possessed by the constituents.

In the modern context, the world has seen a total transformation in materials science and technology and a vast variety of industrially produced composites have come into existence.

The need for utilization of local materials for the manufacture of alternate building elements in countries, where the price of conventional building materials are increasingly high, can not be overemphasized.

In recent times, much research effort in these notations has been directly towards using agro wastes found in plentiful such as rice husk, coffee husks, sawdust, corn granules, etc. as a filler or aggregate in building materials [1].

It is believed that the successful application of agro waste in building materials will not only serve as a cost-effective alternative to the current disposal method, but will also offer a large potential market for its utilization in alternate building materials.

At present, Ethiopia has little experience in the utilization of different construction materials. The conventional materials are produced from mortar, gypsum, clay, limestone and others excavated from the ground. The demand of these building materials which is not compatible with the supply is increasing. This has impact on the rising of cost of cement and other construction materials [2]. This shows a need to focus on alternative building materials produced from raw materials like agro-industrial wastes, and mineral products with relatively low price and much higher strength than the ordinary hollow concrete blocks.

As an effort to partially solve these problems, the Addis Ababa City Government has established an Agrostone Production Center. The Center uses the magnesia cement to bind a variety of inorganic and organic aggregates together. The cement has high early strength, insecticidal properties, resilient, conducting and is unaffected by oil, grease and paints.

Magnesium oxychloride cement, also called magnesia cement, is used as a binder for alternate building materials production. It is formed by the action of concentrated magnesium chloride solution on active magnesium oxide.

The magnesium oxychloride cement has also many superior properties compared to Portland cement. Numerous filler materials like bagasse pumice, red stone, coffee husk, sawdust and sand can be incorporated to impart the desired physical properties of alternative building materials. Recent trends of using light weight partition boards, bind by magnesia cement, and are an eye-opening exercise in the construction industry.

## **1.2 Addis Ababa Housing Development Project Office**

The Addis Ababa City Government along with the Addis Ababa Housing Development Project Office is engaged in the construction of houses to rectify the intensifying housing problems of the city dwellers. The number of housing units valuable in the city are about 60% of the housing needed by the residential or a shortfall of nearly 224 000 houses.

The construction of low-cost houses was taken as an important measure to decipher such a problem. The Agrostone Production Plant, which is expected to relieve problems associated with the dependence of construction projects in the country of cement and concrete blocks, is inaugurated by the Addis Ababa Housing Development Project Office on August 27, 2005.

The limited supply of the existing construction materials coupled with its increasing price is found to be the major challenge in the housing development program that requires the Addis Ababa City Government (AACG) to start assessing different means that can minimize the cost of building materials. One of these efforts is assumed to be an introduction and implementation of an Agrostone technology for the production of different construction materials.

### **The Project Office has the following main objectives:-**

- To produce partition boards, relief and imitation stones;
- To produce light, cheap and environmentally friendly construction materials;
- To use alternative to cement, concrete blocks, corrugated iron roofs, and steel doors;
- To produce partition boards that are easy to fix, lightweight, and that do not require plastering;
- To produce partition boards that are water fire and shock resistant and sound proofs;
- To motivate private investment in the adoption of new technology in the construction materials;
- To construct Agrostone production factories in order to full fill the housing demand for wall construction;
- To construct MgO production factory to secure raw material input of Agrostone production factory;
- To localize all the input materials required for the production of Agrostone partition boards.

## 1.3 Production Technology

### 1.3.1 Agrostone Production Technology

The Chinese technology uses agricultural raw materials as filler, mineral raw material, such as sorrel cement, as binders and bond accelerators and fibreglasses as reinforcement.

The agricultural raw materials can be from different sources as long as it is not chemically reactive and reduces workability. Preferably, raw materials with high tensile strength such as bagasse and coir are important. It has partly reduced the agricultural materials by lightweight mineral fillers and the selected materials are cheap, light and easily available in the country.

Agrostone technology utilizes several admixtures in a very negligible amount to enhance the physical property of the products and make it adaptable to different environmental conditions.

Ethiopia is endowed with a variety of industrial minerals that can be utilized by the Agrostone products. Lightweight mineral fillers such as pumice, red ash, and diatomite are largely available in the country. High quality magnesite deposit is also available in the country.

After intensive researches, laboratory trials and pilot production tests ,it manage to produce magnesium oxide (Mgo) chemicals from the local sources with a quality sufficient enough for the production of magnesia boards. The outcome of such works gives it the courage and the will to erect MgO production factory with a capacity of 10,000 tons/day at Kibre Mengist town near to the vicinity of magnesite quarry/mine.

Production of local Mgo with a capacity of 10,000 tons/year has a net saving of about 20 millions birr per year as compared to the imported MgO. Moreover, it has a saving of about 4kg of MgO for every board of production by using locally produced MgO due to its better quality and reactivity. It has planned to increase the MgO production capacity to nearly 30,000 tons/day in the near future [4].

Magnesium chloride is also found in the Denakil Depression, at the northern part of the country. It is hosted by potash minerals and a large number of potash ore are found in the area. Moreover, Magnesium chloride is found at the mouth of hot brines spreading over the surface. At the current, the Center is using imported magnesium chloride from China. The government established Agrostone building material producing plant.

Why do we prefer Agro stone production technology for Ethiopia?

- ✘ It reduces the construction cost and saves time;
- ✘ It increases the strength of the building and beauty of the house;
- ✘ It comprises five important properties in a single product, i.e. Fire proof, aging proof, crack prevent, shock resistance and non-radiations;
- ✘ It is possible to produce it in different size, shape and forms;
- ✘ It utilizes large labor forces and is convenient for developing countries;
- ✘ It is manufactured from byproduct as well as light and cheap mineral products;
- ✘ It goes inline with mineral resource potential.

The main beneficiaries of this technology are the low-income groups of the community through the housing development program and most of the Government Projects which had vital importance to the community.

At present, the Plant uses the bagasses and pumice which ensures the lightness of the boards produced by keeping a typical mould weight between 40 and 50 kg. In order to make smooth transfer of the technology, appropriate composition and possibilities of other agro wastes as substitutes should be investigated.

### **1.3.2 General Overview of Production Technology**

The technology applies simple machines which can be manually handled and uses large unskilled and semi-skilled labor forces. The full scale production of the boards incorporates more than 300 working forces and a production of 1000 boards per day. The plant involves

local peoples after short training. In addition, the machines can be easily produced locally and are not energy intensive.

The raw materials of the Agrostone production technology are:

**Fillers:** bagasse, pumice.

**Chemical:** Technical grade 87% MgO powder

Technical grade 98% MgCl<sub>2</sub>.6H<sub>2</sub>O flake

Admixtures and auxiliary agents

The Agrostone Plant inputs for the production of boards are shown in Table 1.1 below:

Table 1.1 Basic Raw Materials inputs for the production of Agrostone board [4]

S/N	Description	Standard Consumption Quantity/board (kg)	Weight (%)
1	Magnesium Oxide (MgO)	18.00	41.75
2	Magnesium Chloride (MgCl <sub>2</sub> )	12.51	29.01
3	Fiberglass	1.01	2.34
4	Red ash/pumice	8.33	19.32
5	Bagasse	3.03	7.02
6	Steel bar (4mm)	0.11	0.25
7	Admixtures	0.12	0.27
Total		43.11	100.00

The unit operations of the technology are:

## **A. Raw materials preparation**

### **I. Size reduction**

The raw material bagasse transported from Metara Sugar Factory is size reduced by the hammer mill.

Other filler material i.e. the pumice is crushed by jaw crusher.

### **II. Weighting**

The raw materials are weighed based on their proportions on magnesia cement board composition.

### **B. Mixing**

The  $MgCl_2$  powder dissolves with water and mix to admixtures to enhance the resistance of magnesia cement to water, fire, acid, thermal etc.

The  $MgCl_2$  solution mixed with  $MgO$  powder, and then the pumice and bagasse filler added to the mixed cement paste consecutively in the same mixer.

### **C. Molding**

The mixed paste fill into the mold and a glass fiber is added on the surface to strengthen the material. The molded material stays on the mold for a day and a hollow building material is produced when it dries with open air.

### **D. Soaking and curing**

The soaking pond consists of water and auxiliary agents. The dried product is immersed in a pond for 24 hours and stored in open storage at room temperature for about twenty days to have the required strength in dry curing. Then the building material transport to use as partition board for low cost house building

The process of technology is shown in Figure 1.1

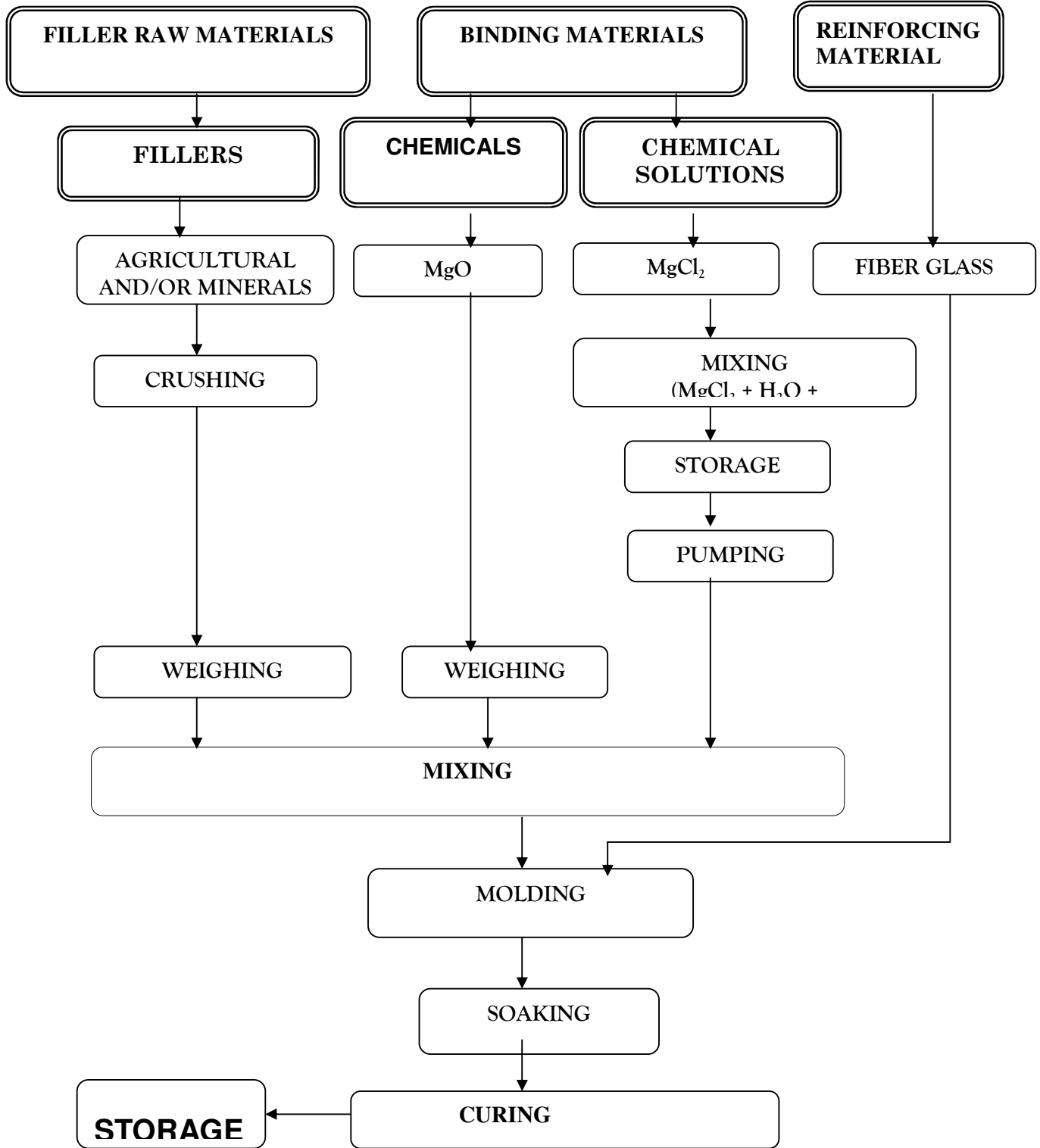


Figure 1.1. Flow diagram of Agrostone production plant.

### 1.3.3 Type of Products

The Agrostone Production Plant produces three major products. These are:

**Partition board:** The partition boards have variable length and thickness but constant width. The length of the boards can vary to a maximum of 3.5m and there are 10cm and 20cm thick boards. The 10cm thick hollow partition board is the common product.

**Relief:** Hundreds of different types of decoration items are available and any one can bring his own design and produce relief. The reliefs include roman colons, roofing materials, wall boards, corner lists etc.

**Doors:** These are light weight doors and have a strength and weather resistant requirement for doors.

The product size and applications of the Agrostone products are shown in Table 1.2

Table 1.2 Size and application of Agrostone products

S/N	Types of Products	Size (TxWxI)	Remarks
1	Partition boards	1. 10x60x250cm 2. 20x60x250cm	Hollow type, variable length 1. Indoor application 2. Outdoors application
2	Decoration reliefs	Various types for decorating building	Applicable for both indoor and outdoors
3	Doors		For internal application

#### 1.3.4 Physical Properties of the Agrostone Products

The physical properties of the Agrostone products as per the test results obtained from different laboratories are:-

- It is non-poison and resistant to radiation;

- It is water and acid resistant and sound proof;
- It can withstand fire up to 118 minutes;
- Dry shrinkage is very small compared to the masonry structures;
- It can carry load weighing 7.3 times its own weight with out bending;
- The binding cement has a comprehensive strength of more than 70Mpa;
- It is shock and impact resistant;
- It has good resistance for single point hanging load.

The technical specification and product standards of products is shown in Table 1.3

Table 1.3 Technical specification and standards of Agrostone products

S/N	TECHNICAL SPECIFICATION	PRODUCT STANDARD
1	Partition Wall (10cm thick) W/m <sup>2</sup>	33Kg/m <sup>2</sup>
2	Bending resistance load	48 times of its weight
3	Shock resistance clashing by 30kg	Clashing 5 times, no cracks
4	Sound insulation	Insulated up to 42DB
5	Fire endurance	Resist Fire for 108 minutes
6	One point hanging	800N hanging, no change after 74 hrs
7	Sudden cold and sudden hot	No change after 20 times recycle
8	Acid and alkali endurance when soaked in 5% HCl and 15% NaOH	Immersed for 7 days, no change
9	Radiation	2.75,2.9,110 <sup>0</sup> C.Kg.h
10	Water of absorption	<22%

(Source: The Science and Technology Department of China)

### 1.3.5 Magnesite Resources of Kenticha Area

Magnesite is the cheapest sources of magnesia (MgO) and the release of CO<sub>2</sub> from this source during firing produce MgO which reacts with MgCl<sub>2</sub> to form magnesia cement. Magnesite is found with dolomitic marble in Kenticha areas, as white, fine to medium grained crystalline rocks. It occurs as linear belt extending for kilometers. Samples collected from this

magnesite occurrences indicated high MgO (40-46%), low Fe<sub>2</sub>O<sub>3</sub> (0.04-0.08 %) and Al<sub>2</sub>O<sub>3</sub> (<0.1%). The magnesite marbles at Kenticha extends for few kilometers. It runs nearly north-south with structural closures at the south. The width of individual bands is generally less than 100 meters. The total indicated resource is about 1.5 million tons. The mineral raw materials are being supplied by the Ethiopian Mineral Resource Share Company.

### **1.3.6 The Manufacturing Process and its environmental impact**

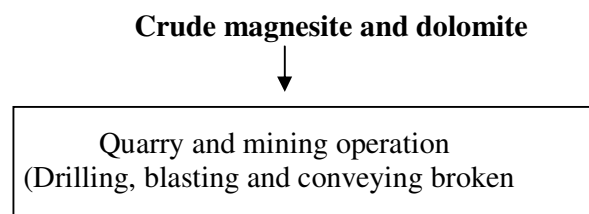
The production of MgO requires the presence of good quality magnesite that should be burnt to produce magnesium oxide. The main objective of this project is to develop an affordable MgO from the local magnesite resources that can be used for the production of partition boards and decoration items.

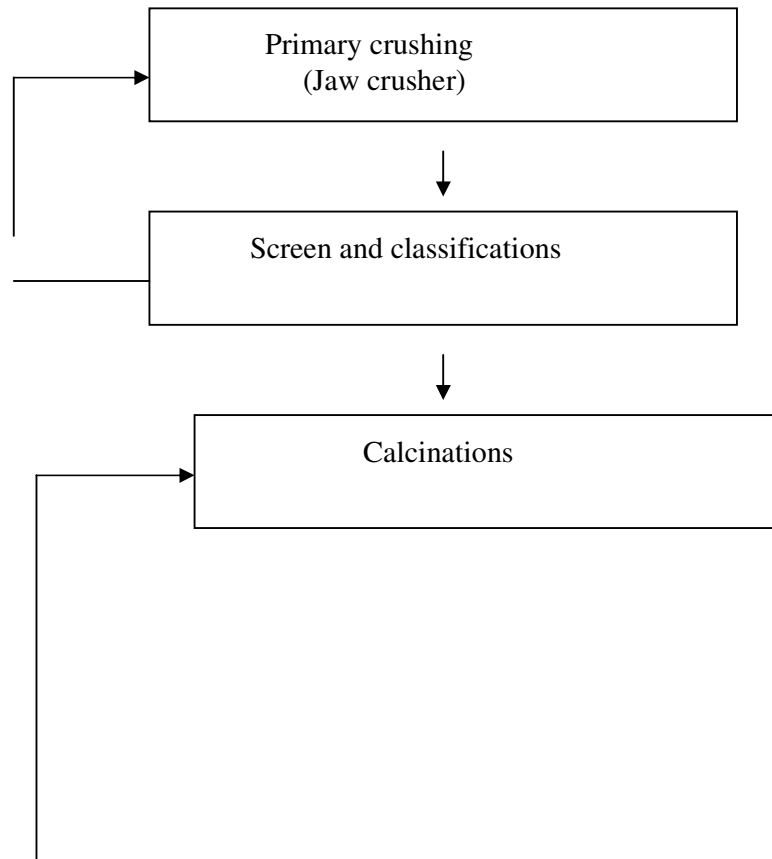
Laboratory trials, locally and abroad, had proved that the Kenticha magnesite is an appropriate material for the production of caustic calcined (light burned) magnesia (MgO) suitable for the production of partition boards and other applications. Moreover, pilot production trial at Ziway caustic soda factory had also proved the technical and economical feasibility of MgO production project with better quality products than the imported magnesium oxide [4].

The basic processes in the production of magnesia are:

- (1) Quarrying raw magnesite;
- (2) Preparing magnesite for the kilns by crushing and sizing;
- (3) Calcining magnesium carbonates; and
- (4) Miscellaneous transfer, storage, and handling operations.

A generalized material flow diagram for a magnesium oxide manufacturing plant in Figure 1.2. The plant is located in the vicinity of kibre Mengist at about 70 km from magnesite source area in Oromo region.





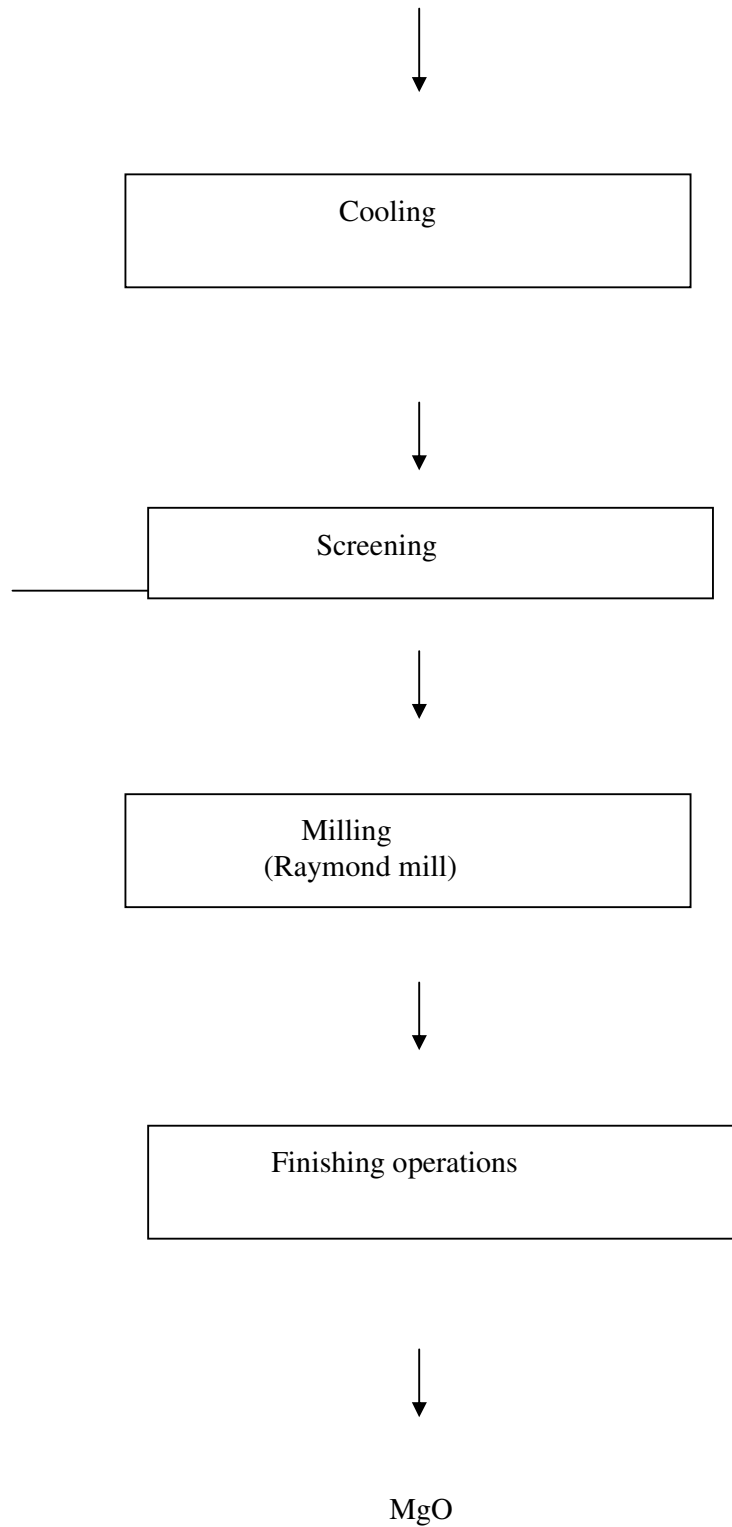


Fig 1.2 Generalized material flow diagram for a magnesium oxide manufacturing plant in the vicinity of Kibre Mengist.

Crude magnesite is fed to a primary crusher whereby the particle size of the crude magnesite is reduced to a size suitable for thermal decomposition (calcinations).

The optimum particle size of the crushed crude magnesite depends upon the type of equipment used for thermal decomposition (calcinations) and normally be 80cm for this vertical kiln. The crushed crude magnesite ore is now thermally decomposed (calcined) in kiln. Fuels, in the form of furnace oil plus excess air are used to fire the kiln.

For calcinations of 1 tone magnesium carbonate, 70-85 liter of furnace oil consumes. The off-gases, containing impure carbon dioxide are formed by the thermal decomposition of the crude magnesite. The temperature and times of calcinations are controlled by the composition of the feed material. The temperature is also controlled by AC converter and cooling fans.

Calcination should be carried out at as low a temperature and for as short a time as it is consistent with the optimum decomposition of the crude magnesite to crude magnesium oxide, the latter having as high a surface area as possible. For Kenticha crude magnesite, that is ore with a magnesite content of about 40-46%, optimum calcinations conditions are of the order of 1060°C for five hour, the actual time depending to some extent on the particle size of the feed material. The calcinations conditions should be such that about 90% of the crude magnesite has been thermally decomposed to crude magnesium oxide. Calcination at a lower temperature or for a substantially shorter time results in a reduced amount of crude magnesite that has been thermally decomposed to crude magnesium oxide. Calcination at higher temperatures or for substantially longer times results in over calcinations; in particular the surface area of the crude magnesium oxide is substantially reduced such that it reacts very slowly with carbon dioxide when it is slurred with water and contacted with the carbon dioxide.

The hot, crude magnesium oxide from the kiln is allowed to cool to room temperature .Its particles reduces to 18cm and then passed to Raymond mill where its particle size is reduced by dry grinding to a size suitable for use , preferably all passing through a 150 micron mesh. Grinding must be carried out in the dry state since if wet grinding is carried out; there is a reaction between the crude magnesium oxide and the water. The magnesium oxide powder extracted from mill is conveyed to the automatic electronic packers where it is packed in 50 Kg and puts in store at room temperature and protect from moisture.

Magnesium is an essential mineral, and with the exception of very high and unusual exposures, ingestion of MgO does not appear to present significant health problem to humans. The inhalation toxicity of magnesium oxide may be influenced by the manufacturing process, which produces grades of magnesium oxide that differ in their physical characteristics.

Humans are potentially exposed to MgO primarily through inhalation of contaminated air. Although dermal contact is possible, and ingestion also occurs through its use as an indirect food additive, these exposures to MgO are unlikely to pose a hazard to humans under normal circumstances.

## **1.4 Statement of Problem**

The current filler raw materials of the Agrostone Production Center are bagasse and pumice. The bagasse is obtained from sugar factory as a byproduct. It uses as fuel for steam production in factory. Hence, its availability depends on the factory demand.

As a result, it is better to think other raw materials as a substitute. For this project, saw dust and coffee husk are selected. They are found as waste of wood work and coffee processing, respectively.

At present, coffee husk generated in the hulling centers is simply being burnt leading to environmental pollution. The quantity of this resource is quite large considering the size of the coffee industry in Ethiopia. Better utilization of this resource can significantly contribute to a higher productivity and profitability as well as improved environmental health.

The effect of using these fillers as sole or mixture with other, in the magnesia cement board should be analyzed to utilize it for different application and to fulfill the required characteristics of building materials.

Hence, the project is needed:

- To have alternative utilization of fillers if scarce of it exists and be able to shift to other fillers.
- To select and utilize fillers and local raw materials for board production economically.

## 1.5 Objective

The objective of the project is to analyze the effect of using different fillers in the production of magnesia cement boards. The effect of fibers and admixtures which are added to improve the water resistance of the cement on the fiber cement board are investigated.

The effect of the use and proportion of different fillers will be examined on these parameters:

- Water absorption;
- Setting time of the paste;
- Compressive and bending strength of the board;
- Production Cost of the boards.

## CHAPTER TWO

### Literature Review Magnesia Cement Board

Magnesia cement board is composed of magnesia cement, fillers and glass fibers.

Magnesia cement-bonded boards were the first inorganic-bonded composite manufactured on a continuous production line. The binder sets within minutes under the influence of higher temperatures. Magnesia cement-bonded particleboards were first described by Simatupang and Schwarz [5].

The major compound of magnesia cement is magnesium oxide. The minor component, about 10 to 15 percent based on magnesium oxide, is an acid radical, generally in the form of a magnesium salt or an ammonium salt. To prepare magnesia cement, a solution of the minor component is mixed with the magnesium oxide. However, magnesia cement can also be prepared by reacting magnesium hydroxide with carbon dioxide and heating the formed reaction product.

#### 2.1 Sorel Cement

Sorel in 1867 announced the discovery of excellent cement formed from the combination of magnesium oxide and magnesium chloride solution.

Sorel cement is a hydraulic cement mixture of magnesium oxide (burnt magnesia) with magnesium chloride together with filler materials like sand or crushed stone. The usual weight ratio 2.5-3.5 parts MgO to one part MgCl<sub>2</sub>. This material is also called magnesia cement. This cement type is known by many different names, such as Sorel, magnesite and magnesium oxychloride cement. This cement has many superior properties to Portland cement.

However, there are two other known magnesia cements. The first is magnesium oxysulfate (MOS), which is the sulfate analogue of magnesium oxychloride and is formed by the combination of magnesium oxide and magnesium sulfate solution. The second is magnesium phosphate cement (MAP), formed by the reaction between magnesium oxide and a soluble phosphate, such as ammonium phosphate monobasic (NH<sub>4</sub>H<sub>2</sub>PO<sub>4</sub>).

##### 2.1.1 Magnesium Oxychloride Cement (MOC)

As mentioned above, magnesium oxychloride has many superior properties compared to Portland cement. It does not need wet curing, has high fire resistance, low thermal conductivity, good resistance to abrasion.

It also has high transverse and crushing strengths, 48-70 MPa are not uncommon. Magnesium oxychloride also bonds very well to a variety of inorganic and organic aggregates, such as, saw dust, wood flour, marble flour, sand and gravel, giving a cement that has high early strength, insecticidal properties, resilient, conducting and is unaffected by oil, grease and paints.

The major commercial applications of magnesium oxychloride cement, are industrial flooring, fire protection, grinding wheels, and because of its resemblance to marble, have been used for rendering wall insulation panels and for stuccos.

The main bonding phases found in hardened cement pastes are  $\text{Mg}(\text{OH})_2$ ,  $3\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2 \cdot 8\text{H}_2\text{O}$  (3-form) and  $5\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2 \cdot 8\text{H}_2\text{O}$  (5-form). 5-form is the phase with superior mechanical properties and is formed using a molar ratio of  $\text{MgO}:\text{MgCl}_2:\text{H}_2\text{O} = 5:1:13$  with a slight excess of MgO and the amount of water as close as possible to theoretical required for formation of the 5-form and hydration of the excess MgO to form  $\text{Mg}(\text{OH})_2$ .

The reactivity of the MgO influence reaction rates and products, thus affecting the development of strengths. The magnesium oxide should conform to certain requirements of chemical and physical properties. Conditions of calcinations, particle size and active lime content must be carefully controlled. Oxymag is a Premier Chemicals magnesium oxide which conforms to the above requirements and is specially produced for making Sorel cements. Magnesium chloride is generally applied as a 22° Be solution and should have a maximum of 0.5% calcium chloride and 1.0% total alkali chlorides. The minimum amount of gauging solution to yield a plastic mix of satisfactory workability should be used.

The main reason why magnesium oxychloride cement has not remained popular in the building industry is that the magnesium oxychloride phase is not stable in prolonged contact with water, and will result in the leaching of magnesium chloride. Various additives have been added to MOC cements to try and combat this problem of water resistance, with varying degrees of success [6].

Over a period of time, atmospheric carbon dioxide will react with magnesium oxychloride to form a surface layer of  $\text{Mg}_2(\text{OH})\text{ClCO}_3 \cdot 3\text{H}_2\text{O}$ . This layer serves to slow the leaching process.

Eventually additional leaching results in the formation of hydromagnesite,  $4\text{MgO}\cdot 3\text{CO}_3\cdot 4\text{H}_2\text{O}$ , which is insoluble and enables the cement to maintain structural integrity.

### **2.1.2 Magnesium Oxysulfate Cements (MOS)**

Magnesium oxysulfates are formulated by the reaction between magnesium oxide and magnesium sulfate solution, and like that of magnesium oxychloride has very good binding properties. The resistance of MOS cements to abrasion is about 1.5 times that of Portland cement, but only 50% that of MOC cement. Its compressive and transverse strengths are superior to Portland cement but not as good as MOC cement.

Four oxysulfate phases are formed at temperatures between  $30^\circ\text{C}$  and  $20^\circ\text{C}$ ;

$5\text{Mg}(\text{OH})_2\cdot\text{MgSO}_4\cdot 3\text{H}_2\text{O}$  (5-form),  $3\text{Mg}(\text{OH})_2\cdot\text{MgSO}_4\cdot 8\text{H}_2\text{O}$  (3-form),  $\text{Mg}(\text{OH})_2\cdot\text{MgSO}_4\cdot 5\text{H}_2\text{O}$ , and  $\text{Mg}(\text{OH})_2\cdot 2\text{MgSO}_4\cdot 3\text{H}_2\text{O}$ . Only the 3-form is stable below  $35^\circ\text{C}$ . The major use of MOS cement is in the manufacture of lightweight insulating panels. Magnesium oxysulfate cement suffers from the same lack of water resistance as do MOC cements.

### **2.1.3 Magnesium Phosphate Cements (MPC)**

Magnesium phosphate cements are formed by the reaction of magnesium oxide with a soluble phosphate, such as ammonium phosphate, either the mono or dibasic salt; or an agricultural fertilizer solution known as 10-34-0 (Nitrogen-Phosphorous –potassium ratio) can also be used. This magnesia cements rapid set and very high early strength has found utility as a rapid patching mortar for road and aircraft run-ways, which can typically be re-opened after about 45 minutes. It has very good adhesion to a wide variety of aggregates and substrates. In contrast to MOC and MOS cements, this cement system has good water and freeze thaw resistance. Commercial magnesium phosphate cements typically reach a compressive strength of about 20 MPa after 1 hour, with an ultimate strength of 55 MPa.

The reaction mechanism is thought to be an acid-base reaction between the MgO and the acid phosphate. This results in an initial gel formation followed by the crystallization of this gel into an insoluble phosphate, mainly magnesium ammonium phosphate hexahydrate,  $\text{NH}_4\text{MgPO}_4\cdot 6\text{H}_2\text{O}$ .

The magnesium oxide used in this system is a fairly unreactive MgO, either hard or dead-burnt, and is used in conjunction with a set retarder, typically either borax or boric acid, to afford a workable set time [6].

## 2.2 Magnesium Oxychloride Cement components

Magnesium Oxychloride Cement is not a product that is commercially available in the prepared form; it must be prepared on site from the raw materials, just before it is required. The setting time varies from 2 to 8 hr; depending on the composition. The result product is hard and strong but does not resist water.

### 2.2.1 Magnesium Oxide

Magnesium oxide (sometimes called magnesia) is formed commercially by heating magnesite, which drives off most of the  $\text{CO}_2$ . It has good thermal conductivity and electrical resistivity at elevated temperatures. Magnesium oxide is used as a basic refractory material for lining crucibles. Magnesium oxide is a principal ingredient in construction materials used for fireproofing. It is used as a reference white colour in colorimetry. The emissivity value is about 0.9.

Magnesium oxide seldom occurs as a natural mineral; it is found in contact metamorphic lime stone and dolomites, in volcanic eject, and in serpentine rocks. It does not form rocks or salt deposits because it converts to magnesium hydroxide by the water vapor in the atmosphere. The primary sources of industrially produced magnesia are natural magnesite, seawater and natural and synthetic brines. Natural magnesite is a mineral composed of  $\text{MgCO}_3$  and its theoretical composition is 47.8% MgO and 52.2%  $\text{CO}_2$ . Magnesium hydroxide is formed as an intermediate in the production of magnesia from sea water and brines. Magnesia is used in technical application on accounts of its high melting point, chemical resistance, high thermal conductivity, low electrical conductivity and biological activity.

Technical grade magnesia is mainly sintered to form sintered magnesia (also known as magnesia sinter, dead-burned magnesia or sintered magnesite) which is used primarily as a refractory material and in the steel industry. Large quantities of calcined (decarbonated) material known as caustic magnesia or caustic-calcined magnesia are produced for use in agriculture and building industry. Fused magnesia is normally produced by melting caustic magnesia.

Table 2.1 Physical and thermochemistry of magnesium oxide [7]

Name	Magnesium oxide
<a href="#">Chemical formula</a>	<a href="#">MgO</a>

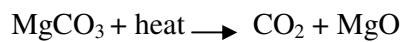
Common Reaction	$2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$
<a href="#">Appearance</a>	White, Powder
<b>Physical</b>	
<a href="#">Formula weight</a>	40.3044 g/mol
<a href="#">Melting point</a>	3073 K (2800 °C)
<a href="#">Boiling point</a>	3873 K (3600 °C)
<a href="#">Density</a>	3580 kg/m <sup>3</sup>
<a href="#">Crystal structure</a>	Cubic FCC
<a href="#">Solubility</a>	0.00062 g in 100 g water
<b>Thermochemistry</b>	
$\Delta_f H_{\text{solid}}^0$	-601 kJ/mol
$S_{\text{solid}}^0$	32.51 J/(mol·K)
<b>Miscellaneous</b>	
<a href="#">Thermal conductivity</a>	42 W m <sup>-1</sup> K <sup>-1</sup> at 0 °C
<a href="#">Coefficient of thermal expansion<sup>[1]</sup></a>	9.84 × 10 <sup>-6</sup> /K at 0 °C
<a href="#">Specific heat capacity</a>	877 J kg <sup>-1</sup> K <sup>-1</sup>
<a href="#">Dielectric constant</a>	9.65 at 1 MHz
<a href="#">Young's modulus</a>	250 GPa
Shear Modulus	155 GPa

Two methods of production of magnesium oxide are exists.

**1. Production of magnesium oxide from crude magnesite and dolomite:**

The production of MgO utilizes magnesite ( $\text{MgCO}_3$ ) as the main input material and furnace oil as energy source. The production process involves decomposition of the  $\text{MgCO}_3$  to MgO and  $\text{CO}_2$  and hence the release of  $\text{CO}_2$  to the atmosphere in the form of gas. All sorts of calcinations process which involves the input of carbonate rocks undertake the same phenomena. The final product will be subjected to milling for size reduction until 85% the materials pass the 150um sieve openings.

Magnesium oxide is the high-temperature product of the calcinations of magnesium carbonates. Although magnesite deposits are found in every state, only a small portion is pure enough for industrial magnesia manufacturing. To be classified as magnesite, the rock must contain at least 50 percent magnesium carbonate. When the rock contains 30 to 45 percent magnesium carbonate, it is referred to as dolomite. Magnesium oxide is manufactured in various kinds of kilns by one of the following reactions:



## **2. Production of Magnesium Oxide from brine:**

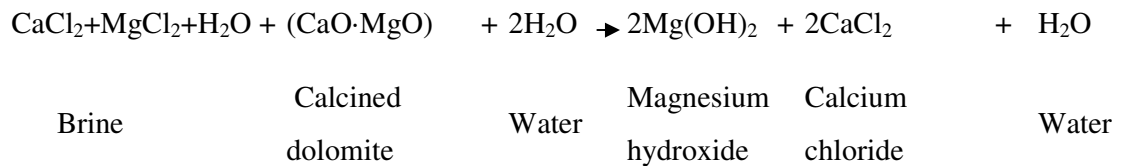
While mining is one source, another important source of magnesium oxide is obtained from processing seawater and underground deposits of brine which contain magnesium chloride. The remainder of this summary will follow the extraction and processing of magnesium oxide from a typical brine source. The process for extraction from seawater would follow basically the same route, differing only in the concentration of magnesium in seawater.

Brine is essentially a saturated salt solution which, in this case, contains magnesium chloride, calcium chloride and water. Since the concentration of magnesium in this brine source is around 9%, it takes about 10 liters of brine to produce just 0.5 kg of magnesium oxide.

In order to extract magnesium from brine, another ingredient is needed. Typically this ingredient is lime or calcium oxide ( $\text{CaO}$ ) which is obtained from a mineral source such as dolomitic limestone ( $\text{CaMg}(\text{CO}_3)_2$ ). When heated to high temperatures the carbon dioxide is driven off leaving calcined dolomite in the above reaction.

First, naturally occurring brine is mixed with both calcined dolomite and water to produce an

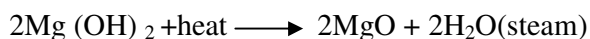
aqueous suspension containing magnesium hydroxide and calcium chloride:



The magnesium hydroxide and calcium chloride produced from this reaction exist together but in two distinct physical states: magnesium hydroxide is formed as solid particles while the calcium chloride is dissolved in the liquid or watery phase. An aqueous suspension containing solid particles is also referred to as a slurry.

Gravity is used to separate the solids from the liquid in the aqueous suspension since magnesium hydroxide is heavier than water. If you look at a bottle of milk of magnesia, which you probably have in your bathroom medicine chest, you'll see this separation clearly. Milk of magnesia is another name for magnesium hydroxide. The blue color indicates the watery layer containing dissolved magnesium chloride that has formed above the settled magnesium hydroxide particles.

The bottom solids are then filtered to remove any remaining water and given a series of water washes to remove chlorides from the material. This results in a damp filter cake which can be seen dropping off the lower roller of the press about waist high to the operator. The washed filter cake is finally directed to a source of heat, such as a rotary kiln, where it is thermally decomposed (calcined) to produce magnesium oxide:



The original or "parent" magnesium hydroxide particle is usually a large and loosely bonded particle. Exposure to thermal degradation causes this particle to alter its structure so that the surface pores are slowly filled in while the particle edges become more rounded.

Thermal alteration dramatically affects the reactivity of magnesium oxide since less surface area and pores are available for reaction with other compounds.

Several types of kilns can be used in the calcinations step. Calcinations not only convert magnesium hydroxide to magnesium oxide, but are also the most important step for determining how the final product will be used [7].

### **Different grades of magnesium oxide**

Three basic types or grades of "burned" magnesium oxide can be obtained from the calcinations step with the differences between each grade related to the degree of reactivity remaining after being exposed to a range of extremely high temperatures.

### **Dead burned magnesium oxide (Sintered magnesia)**

Most (about 85%)  $MgCO_3$  and  $Mg(OH)_3$  is converted into sintered magnesia (also known as magnesia clinker or dead burned magnesia). Sinter quality depends not only on chemical composition but also on the bulk density or porosity; a high density gives a better product. Sintering capability decreases considerably with increasing purity, making a high density difficult to achieve. The final bulk density of the sinter depends on chemical composition, sintering temperature and time and the degree of compression of materials prior to sintering. The material is usually sintered in lamp form.

Temperatures used when calcining to produce refractory grade magnesia will range between  $1500^{\circ}C$  -  $2000^{\circ}C$  and the magnesium oxide is referred to as "dead-burned" since most, if not all, of the reactivity has been eliminated. Refractory grade  $MgO$  is used extensively in steel production to serve as both protective and replaceable linings for equipment used to handle molten steel.

Magnesite Grain- dead-burned magnesia in granular form in size is suitable for refractory purposes.

Seawater Magnesite- Dead-burned magnesia made by a chemical process using seawater or other solutions (brines).

### **Hard burned magnesium oxide**

A second type of magnesium oxide produced from calcining at temperatures ranging from  $1000^{\circ}C$  -  $1500^{\circ}C$  is termed "hard-burned". Hard burned caustic magnesia has a loose bulk density of  $1200kg/m^3$  (bulk density  $2000kg/m^3$ ).

Due to its narrow range of reactivity, this grade is typically used in applications where slow degradation or chemical reactivity is required such as with animal feeds and fertilizers.

### **Light burned magnesium oxide**

The third grade of MgO is produced by calcining at temperatures ranging from 600°C - 1000°C and is termed "light-burn" or "caustic" magnesia. Due to the material's wide reactivity range, industrial applications are quite varied and include plastics, rubber, paper and pulp processing, steel boiler additives, adhesives, and acid neutralization to name just a few.

Caustic magnesia is a vary reactive, finely crystalline material that is produced by burning MgCO<sub>3</sub> or Mg(OH)<sub>2</sub> slightly above the decomposition temperature. Caustic magnesia was formerly produced exclusively from cryptocrystalline magnesite with a low iron content but is now also obtained from all types of magnesite and Mg(OH)<sub>2</sub>.

Its MgO content ranges from 65 to 99 wt % and may even reach 99.9%.The magnesia is often ground prior to use. Extreme reactive caustic magnesia may have a surface area of up to 160m<sup>2</sup>/g.

Caustic magnesia is produced industrially by calcining lump MgCO<sub>3</sub> (up to 50mm) or finer material in shaft, rotary or multiple –hearth kilns. Heat exchange kilns are also employed .

In the case of Mg(OH)<sub>2</sub>, dewatered filter cakes are usually calcined in lump form at about 950<sup>0</sup>C in multiple hearth kilns. These kilns generally contain ten shelves (hearths), one above the other; each hearth is provided with four burners in the vertical cylindrical kiln wall.

The material is feed continuously into the top of the kiln and its residence time can be adjusted via the rake that rotates above each hearth. The calcining condition must be carefully adapted to the contaminants in the feed otherwise over burning results in excess growth of the reactive MgO crystallites which lowers their activity.

When heated from 600°C to 1000°C, magnesium carbonate thermally decomposes to produce magnesium oxide and carbon dioxide:



Light burned caustic magnesia becomes hydrated in cold water and is soluble in dilute acid. It has a loose bulk density of 300-500 kg/m<sup>3</sup> and a specific surface area of 10-65m<sup>2</sup>/g [8].

## 2.2.2 Magnesium chloride

Magnesium chloride is the name for the chemical compounds with the formulas MgCl<sub>2</sub> and its hydrates MgCl<sub>2</sub>(H<sub>2</sub>O)<sub>x</sub>. These salts are typical ionic halides, being highly soluble in water. It is a constituent of many salt lakes and natural brines. Sea salt contains 17 % magnesium

chloride. Mineral salt deposits contains the important mineral carnallite  $\text{KCl}\cdot\text{MgCl}_2\cdot 6\text{H}_2\text{O}$ , bischofite  $\text{MgCl}_2\cdot 6\text{H}_2\text{O}$  and occasionally the double salt anhydrites in which the magnesium chloride is combined with calcium chloride ( $\text{CaCl}_2\cdot 2\text{MgCl}_2\cdot 12\text{H}_2\text{O}$ ). Magnesium chloride is obtained from mineral salt deposited by processing the spent liquors remaining after extraction of potassium chloride and also by direct solution mining; it is also recovered from salt lakes and sea water.

$\text{MgCl}_2$  crystallizes in the cadmium chloride, which features octahedral Mg. In the hexahydrate, the  $\text{Mg}^{2+}$  remains octahedral, but coordinated to six water ligands. A variety of hydrates are known with the formula  $\text{MgCl}_2(\text{H}_2\text{O})_x$ , and each loses water with increasing temperature:  $x = 12$  ( $-16.4^\circ\text{C}$ ),  $8$  ( $-3.4^\circ\text{C}$ ),  $6$  ( $116.7^\circ\text{C}$ ),  $4$  ( $181^\circ\text{C}$ ),  $2$  ( $300^\circ\text{C}$ ).

As suggested by its tendency to form octahedral complexes,  $\text{MgCl}_2$ , especially when anhydrous, is a weak Lewis acid [9].

A number of methods have been followed in the past for the production of magnesium chloride hexahydrate. One of the most common techniques involves the evaporation of sea water and natural brines, but this has heretofore only been economical where the dilute solutions can be preconcentrated by solar evaporation. In one specific example of this process, brine from the Great Salt Lake containing approximately 35% by weight  $\text{MgCl}_2$  solution (nominally  $\text{MgCl}_2\cdot 12\text{H}_2\text{O}$ ) is first subjected to solar evaporation, followed by vacuum evaporation until the 6-hydrated form of  $\text{MgCl}_2$  and  $\text{MgSO}_4$  are precipitated.

Thereafter, the precipitated crystals are heated to  $120^\circ\text{--}150^\circ\text{C}$  to redissolve the  $\text{MgCl}_2\cdot 6\text{H}_2\text{O}$  and allow removal of magnesium sulfate. The  $\text{MgCl}_2\cdot 6\text{H}_2\text{O}$  can then be crystallized out. Alternately, the initially evaporated solution can be maintained at  $120^\circ\text{C}$  until the magnesium sulfate content decreases to less than 20 g/L as a result of crystallization of kieserite. The  $\text{MgCl}_2\cdot 6\text{H}_2\text{O}$  is then crystallized by vacuum evaporation at  $90^\circ\text{C}$ .

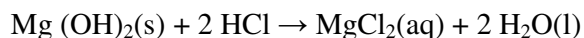
The prime difficulty with evaporative processes of this type stems from the high energy input and hence costs associated with the ultimate production of  $\text{MgCl}_2\cdot 6\text{H}_2\text{O}$ . Indeed, the cost of brine dehydration is by far the most significant expense associated with production of the desired product [10].

It has also been known to manufacture magnesium chloride as a by-product of the potash industry or by direct chlorination of magnesium oxide in the presence of an organic reducing agent. However, these methods are generally even more expensive than those involving evaporation of brines.

In a similar fashion, salts such as calcium chloride have been produced in commercial quantities by a number of processes including the refining of natural brines, reaction of calcium hydroxide with ammonium chloride in Solvay soda ash production, and the reaction of hydrochloric acid with calcium carbonate. Here again, the brine processes are relatively expensive, and involve multiple steps such as reaction of the brines with lime and subsequent concentration.

There is therefore a need in the art for a simplified, low cost process for the production of alkaline earth metal salts, and particularly  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ , which avoids multiple, energy-intensive evaporation and/or chemical separation steps.

As mentioned above, the direct production of  $\text{MgCl}_2$  from seawater or brines by evaporation is only economical where the dilute solutions can be preconcentrated by solar evaporations. If sea water cannot be preconcentrated by solar energy, magnesium chloride salt or solution can only be produced in large scale by precipitation as the hydroxide, followed by conversion to the chloride with hydrogen chloride [11]. That is in the Dow process, magnesium chloride is regenerated from magnesium hydroxide using hydrochloric acid:



It can also be prepared from magnesium carbonate by a similar reaction.

Magnesium chloride is used as a gauging solution for the production of oxychloride cement for flooring, plaster, fire resistance panels, etc.

### 2.3 Fillers

Filler is a component which does not participate, or only slightly participate in the hardening reaction of the hydraulically active component. However, as a result of its physical properties especially its particle size distribution, it improves the properties of fresh and hardened cement paste, mortar, or concrete.

It is effective because it can be incorporated into the hollow space between the cement particles. In this way, the space which must be first be filled by the mixing solution and during hardening by the hydration products of cement can be reduced.

Thus the fillers helps to form a denser structure, therefore, the filler can increase the strength to a limited extent without taking part in the hardening reactions.

Depend on oxychloric (Sorel) cement end use, four groups of ingredients combined in its formulation: inert fillers ( marble flour, talc); fibrous fillers (asbestos, bagasse, wood flour, saw dust), which are good for marble floors; inert aggregates (sand, crushed stone) and inorganic alkali resistant pigments. The fibrous material in the composite can act both as an aggregate and as a reinforcing material. In either case the interaction between the binder and the fiber material is very important. Certain fibers and their extractives retard the cure of inorganic binders. Fiber extractives retard the hydration of the inorganic binders and alter crystalline structure [12].

Some of fillers that are used in this research are mentioned below.

### **2.3.1 Bagasse**

Bagasse is the residue fiber remaining when sugarcane is pressed to extract the sugar. Some bagasse is burned to supply heat to the sugar refining operation. Some is returned to the fields, and some finds its way into various board products. Bagasse is composed of fiber and pith. The fiber is thick walled and relatively long (1-4mm). For use in composites, fibers are obtained mostly from the rind, but there are fibro vascular bundles dispersed throughout the interior of the stalk as well.

Bagasse is available wherever sugarcane is grown. As such, almost no harvesting problems exist, and large volumes are available at sugar mills.

#### **Chemistry and Composition of Bagasse**

Bagasse contains about 40 % cellulose, 30 % hemicellulose, and 15% lignin. Bagasse fiber is similar to cotton fiber in that it has a spiral structure (length = 0.13 -0.38cm, width = 0.013-0.038 cm). Cellulose is a linear polyglucose and is highly hydrogen bonded component. Therefore, it is a highly crystalline, stable polymer and highly resistant to solvent and chemical attack.

Hemicelluloses are also polymers but may contain several different sugar units and their degree of polymerization is low. They are not crystalline and are not resistant to solvent and chemical attack.

Lignins are complex, cross linked polymers of phenylpropanoid units joined by benzylic and phenolic ether linkages and C-C linkages [12].

Analysis of bagasse from Wonji/Methra Sugar factories show that there exist 46.5% of fibers in bagasse [13].

### 2.3.2 Pumice

Pumice is a highly vesicular pyroclastic igneous rock of intermediate to siliceous magmas including rhyolite, trachyte and phonolite. Pumice is usually light in color ranging from white, yellowish, gray, gray brown, and a dull red. Most of the time, it is white. Its chemical name is amorphous aluminum silicate. As an extrusive rock it was made from a volcanic eruption.

Pumice has an average porosity of 90%. Pumice is formed as pyroclastic material is ejected into the air as a froth containing masses of gas bubbles or vesicles, the lava solidifies quickly and the vesicles are contained in the rock. The basaltic version of pumice is known as scoria and has many differences due to mineralogy. When larger amounts of gas are present, the result is a finer-grained variety of pumice known as pumicite. Pumice is considered a glass because it has no crystal structure. Pumice varies in density according to the thickness of the solid material between the bubbles; many samples float in water [14]. Table 2.2 shows some of the physical constants of pumice.

Pumice is one of the natural pozzolanic material which are vitreous product consisting mainly of silica and alumina ,have an acidic character and great affinity for lime and alkali.

A pozzolanic material possesses little or no cementitious property but which will, in finely divided form and in the presence of moisture ,chemically react with CaOH at ordinary temperature to form compound possessing cementing properties.

It is found in different areas in Ethiopia and its compositions varies depends on the locations where it founds. Some typical compositions of pumice deposited in Ethiopia are shown in Table 2.3.

Table2.2 Physical constants of pumice

Bulk Density (g/cm <sup>3</sup> )	Very low
-----------------------------------	----------

Mohs Hardness @20°C	5.5
Specific Gravity (g/cc)	2.3-2.4
pH	7.2
Particle Shape	Irregular
Loss On Ignition	5%

Table 2.3 Typical Chemical composition of pumice deposited in Ethiopia [15]

### 2.3.3 Sawdust

Sawdust is a dust or small fragments of woods made by a saw in cutting. As a result, it has the character of the wood that it gets from. Historically, wood has been used in a variety of applications ranging from engineering material to a source of energy. Wood is one of the oldest and most widely used construction materials and today is just available as an

Location	Mass percent (weighted average)								
	LOI	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O
Methara	4.6	68.8	9.9	4.7	1.8	0.6	----	4.6	4.5
Koka	5.9	61.5	4.1	3.0	1.5	0.6	----	4.2	----
Kimbibit	4.1	64.6	16.3	3.9	1.7	2.5	----	4.2	---

engineering material. Wood is hygroscopic. Its affinity for water is greatest when completely dry and zero when it reaches saturations or its fiber saturation point.

Wood is composed of varieties of substances. In its dry state, the chief constituents are cellulose, lignin, hemicelluloses, extractives and various ash forming minerals.

The major constituent is cellulose, which comprise about 50-70% of the wood; cellulose is basically a high molecular weight polymer believed to have a straight chain molecular configurations. It is subdivided into two types; alpha-cellulose and hemicellulose.

Alpha-cellulose is the base of paper, paper pulp product, synthetic textile and plastics. At present, hemicellulose is little used; perhaps through continued research its complete utilization can be realized. In the presence of mineral acids, cellulose degrades to sugar glucose. During the normal growth cycle of tree, the cellulose molecular chain becomes

oriented to a highly structure strands(called fibrils).Fibrils are ,in turn organized, into larger structural elements, which comprises the cell wall of wood fibers.

Cellulose is insoluble in water and in neutral organic solvents (gasoline, alcohol, benzene, ether, carbon tetrachloride). It is insoluble nearly insoluble in cold dilute aqueous acids and alkalis. It will dissolve in 72-75% strength sulfuric acid and 44% hydrochloric acid.

Lignin is the next largest chemical constituent in woods .Its content varies considerably among wood species. Soft wood contains 23 to 33 % lignin, where as hardwood species vary from 16 to 25%. Lignin is a macro molecular constituent that exists largely as a an intercellular material. It has a three -dimensional molecular configurations that is relatively complex and only superficially understood. It is basically an insoluble material believed to be loosely bonded to cellulose. Lignin is the adhesive that gives strength and rigidity to the wood.

Hemicelluloses are polymeric units that are built up from simple sugar molecules. They differ from cellulose in that they yield several type of sugar when reacted with acids. The relative amounts of these sugars vary greatly with wood species.

For hardwoods, roughly 20-30% of hemicellulose are present, with xylose comprising the principal suger.The main polymer chain has also been associated with lesser, but significant amount of arabinose,mannose and sugar acid .

Softwood trees have been reported to have 15-20% hemicellulose ,with the main sugar units being mannose, lesser amount of xylose ,arabinose and sugar acid have also been found in soft woods.

Extractive are not part of the wood structure but important to various wood properties, such as color odour, taste, resistance, decay, strength, density and flammability. They consist of tannins, starch coloring material, oils, resins fats and waxes.

The extractives range from 5-30% among wood species. Their concentration also depend on growth condition, such as climate and soil characteristics and the season in which tree is cut. They can be removed from wood by neutral solvents, water, alcohol, acetone benzene and ether. Minor constituents, such as ash- forming minerals, generally comprise up from 0.1 to 3% of the wood. Common constituents are silica, phosphates potassium and calcium [16].

#### **2.3.4 Coffee husk**

Coffee fruits can be processed by either wet or dry processing methods. In the majority of coffee farms, fruits are dried naturally (sun-dried) or artificially (in furnaces). To obtain the seeds (beans), the exocarp, mesocarp and endocarp of the dried cherry coffee must have to be removed by hulling, originating the so called husk. In the wet processing procedure the fruits are pulped, fermented, washed and sun or artificially –dried; the pulping procedure removes the exocarp and most of the mesocarp, resulting in the so-called coffee pulp. Part of the mesocarp remains adhered to the endocarp, and is lost by fermentation and subsequent washing. The dried coffee in the wet processing procedure is called dry parchment coffee, because the endocarp (parchment) is not removed; hulling the dry parchment coffee originates what is called hulls.

The parchment is very rich in cellulose, and compared to exocarp and endocarp, it does not contribute significantly to the total fruit weight. Therefore, husk and pulp are the main by-products of the coffee processing.

Pulp undergoes intense microbial fermentation and certainly has remarkable chemical differences in comparison to husk, although some degree of fermentation may also occur natural drying. Exocarp, plus mesocarp and endocarp represent 60% of the dried fruit mass. Therefore, a considerable volume of husk is produced when coffee fruit is processed.

Most coffee farms use the husk as organic fertilizer, broadcasting it through out coffee plantations soils. However, despite its good chemical composition in comparing to with other organic fertilizers, mainly regarding N and K contents, the husk has the inconvenience of being bulky, making storage, handling and soil incorporation a problem, only part of the produced husk is used as fertilizer.

The coffee husk contains 31% fibers and 23% reducing sugars(dry matter basis) .The ash content is also considerably high (11%). The high concentration of organic component in coffee husk makes it an important substrate for its applications as animal feed or bioprocess.

Coffee husk contents are for carbohydrates (57.8%), proteins (9.2%), fat (2%), caffeine (1.3%), tannins (4.5%) and pectin (12.4%) in dry mater basis [17].

## **2.4 Glass Fibers**

The fiber accomplishes reinforcement of the binders, provision of the majority of the strength and stiffness of a composite. It carries the majority of the loading and which inherently have superior property to the bulk fiber material. Glass fibers are among the most versatile

industrial fiber known today. They are readily produced from raw materials, which are available in virtually unlimited supply.

All glass fibers described in this paper are derived from compositions containing silica. They exhibit useful bulk properties such as hardness, transparency, resistance to chemical attack, stability, and inertness, as well as desirable fiber properties such as strength, flexibility, and stiffness. Glass fibers are used in the manufacture of structural composites, printed circuit boards and a wide range of special-purpose products.

**Fiber Forming Processes:** Glass melts are made by fusing (co-melting) silica with minerals, which contain the oxides needed to form a given composition.

The molten mass is rapidly cooled to prevent crystallization and formed into glass fibers by a process also known as fiberization.

Nearly all continuous glass fibers are made by a direct draw process and formed by extruding molten glass through a platinum alloy bushing that may contain up to several thousand individual orifices, each being 0.793 to 3.175 mm in diameter. While still highly viscous, the resulting fibers are rapidly drawn to a fine diameter and solidify. Typical fiber diameters range from 3 to 20  $\mu\text{m}$ . Individual filaments are combined into multifilament strands, which are pulled by mechanical winders at velocities of up to 61 m/s and wound onto tubes or forming packages.

The marble melt process can be used to form special-purpose, for example, high-strength fibers. In this process, the raw materials are melted and solid glass marbles, usually 2 to 3cm in diameter, are formed from the melt. The marbles are remelted (at the same or at a different location) and formed into glass fibers. Glass fibers can also be down drawn from the surface of solid preforms.

Although this is the only process used for manufacturing optical fibers, it is a specialty process for manufacturing structural glass fibers such as silica or quartz glass fibers.

**Sizes and Binders:** Glass filaments are highly abrasive to each other. 'Size' coatings or binders are therefore applied before the strand is gathered to minimize degradation of filament strength that would otherwise be caused by filament-to-filament abrasion.

Binders provide lubrication, protection, and/or coupling. The size may be temporary, as in the form of a starch-oil emulsion that is subsequently removed by heating and replaced with a

glass-to-resin coupling agent known as a finish. On the other hand, the size may be a compatible treatment that performs several necessary functions during the subsequent forming operation and which, during impregnation, acts as a coupling agent to the resin being reinforced.

**Glass Fiber Types**

Glass fibers fall into two categories, low-cost general-purpose fibers and premium special-purpose fibers. Over 90% of all glass fibers are general- purpose products. These fibers are known by the designation E-glass and are subject to ASTM specifications. The remaining glass fibers are premium special-purpose products [18].

Many, like E-glass, have letter designations implying special properties. Some have trade names, but not all are subject to ASTM specifications. Specifically:

<b>Letter designation</b>	<b>Property or characteristic</b>
E, electrical	Low electrical conductivity
S, strength	High strength
C, chemical	High chemical durability
M , modules	High stiffness
A , alkali	High alkali or soda lime glass
D, dielectric	Low dielectric constant

**2.5 Mechanisms of Magnesia Cement Productions**

Sorel cement is a term used to refer to various cured compositions having as basic ingredients a combination of magnesia (MgO) and magnesium chloride (MgCl<sub>2</sub>). This basic Sorel system when cured is magnesium oxychloride hydrate.

The process for producing magnesium oxychloride hydrate cements which involves forming a mixture of water, magnesium chloride hydrate and magnesium oxide in which a minor portion of the magnesium oxide is treated to render it initially substantially unreactive with the magnesium chloride hydrate but capable of slowly reacting with the magnesium chloride

hydrate after the initial exothermic reaction of the reactive portion of the magnesium oxide with the magnesium chloride hydrate [19].

The magnesium oxide and the magnesium chloride solution should preferably be kept separately and only combined on the job site or at least in the vicinity of the job site. When these ingredients precombined, deleterious effects, such as a pre-cementing action and water absorption problems, would most certainly occur.

It will be understood that there is no direct affinity between magnesium oxide and magnesium chloride when both are in a dry state. When water is added, a chemical bond is formed between the two constituents to constitute the magnesium oxychloride cement. It is believed that the resulting cement composition has a chemical formula of either  $3\text{MgO} \cdot \text{MgCl}_2 \cdot 11\text{H}_2\text{O}$  or  $5\text{MgO} \cdot \text{MgCl}_2 \cdot 13\text{H}_2\text{O}$  or a combination thereof. It will be appreciated that 11 or 13 molecules of water are necessary to form the cementitious molecule. The six waters of hydration normally associated with magnesium chloride crystals are not sufficient for the chemical bond, and the necessity for the presence of a suitable amount of additional water is apparent. Therefore, a magnesium chloride solution having a proper ratio of magnesium chloride to water is important to achieve a proper cementing reaction.

It is important to note that water should not be first mixed with the magnesium oxide prior to adding magnesium chloride, since the magnesium oxide tends to hydrate and become magnesium hydroxide upon the addition of water. Magnesium hydroxide is a totally different compound than magnesium oxide, it is insoluble in water, and it does not combine with cement magnesium chloride to form an oxychloride.

The magnesium chloride solution should have a specific gravity in the range from about  $20^\circ \text{Be}$  (sp. gravity =1.176) to about  $30^\circ \text{Be}$  (sp. gravity =1.261), and preferably in the range from about  $21^\circ \text{Be}$  (sp. gravity =1.179) to about  $26^\circ \text{Be}$  (sp. gravity =1.218), depending on the desired strength of the product.

When the specific gravity of the solution exceeds the suitable range (that is, the solution has a very high degree Baume) the excess magnesium chloride will tend to absorb the moisture from the atmosphere causing the surface of the cement to expand slightly or otherwise become irregular.

Similarly, if the specific gravity of the magnesium chloride solution is below the suitable range, then there will be unreacted magnesium oxide present which will tend to combine with water in the solution to form either oxychloride cement or magnesium hydroxide, otherwise, there will be excess water which must evaporate, slowing the curing time of the cement.

As discussed above, magnesium hydroxide has no cement bonding properties with the magnesium chloride and water. Therefore, if an excessive amount of magnesium hydroxide is present, fissures and warping tend to occur rendering the quality of the concrete unacceptable.

Based upon the foregoing and previous tests, the preferable range of specific gravity for the magnesium chloride solution is in the range from about 21° Be to about 26° Be. This range provides adequate strength for most practicable uses.

Several factors are involved in determining the preferable range of specific gravity.

One of the most important factors in the use of magnesium oxychloride cements, discussed above, is to achieve the best possible balance between magnesium oxide and magnesium chloride in order to produce a complete chemical reaction.

Another important factor in determining a preferable specific gravity is the total cost of the cement composition. When a higher concentration of magnesium chloride is used, the amount of magnesium oxide must be increased to maintain the stoichiometric balance. If higher concentrations of magnesium chloride and magnesium oxide are used, the cost of the cement product is increased.

The costs for the cement composition ingredients should preferably be held as low as possible, commensurate with the desired strength, to make the end products cost-competitive. Increasing the degree of Baume [see Appendix B] from 24° to 30° would increase the overall cost of the cement product by about 20% [20].

It is believed that Sorel cement consists essentially of a combination of magnesium oxide (MgO), magnesium chloride (MgCl<sub>2</sub>) and water (H<sub>2</sub>O) in which the reactions that take place when these three components are mixed are, in the most simple terms, as follows:

- (1) Solution of magnesium oxide;
- (2) Hydration of magnesium oxychloride; and finally
- (3) Precipitation of magnesium oxychloride hydrate.

The material thus formed has been found to have an intermeshed crystal structure whose properties depend on its density and the bond between the crystals.

It is assumed that it is the hydration reaction that is exothermic and which produces the magnesium oxychloride hydrate crystals of the Sorel cement. But this hydration can occur only after sufficient MgO has dissolved to form an aqueous ion mix that is supersaturated with respect to the oxychloride hydrate. Once hydration becomes dominant, the free water is removed and the dissolution of MgO stops. If, at this time, insufficient MgO has dissolved to react with all the MgCl<sub>2</sub> present, then the end product will consist of an intimate mixture of crystals of magnesium oxide, magnesium chloride hydrate and magnesium oxychloride hydrate. This material would be weak because the residual MgO cannot contribute to the new crystal entanglement, and hence to the strength and stability of the cement, and it would be very sensitive to water exposure since the magnesium chloride is soluble and is easily leached out, eliminating the necessary intimate contact between the magnesium oxychloride hydrate crystals which is responsible for the stability and strength of the end-product cement material.

The present invention is directed to an improved water and weather resistant cured Sorel cement product having improved strength, and to improvements in the process for producing Sorel cement compositions, for the control of the viscosity, pot life and exothermic reaction, all of which are necessary for a practical production process.

According to the present invention, a premix is prepared by mixing water, a minor portion of the total required MgO, and a reaction inhibitor. The premix is allowed to stand a short time to allow the reaction inhibitor to take effect; the MgCl<sub>2</sub>.6H<sub>2</sub>O is then added to the premix together with the balance of the MgO and any other ingredients desired, such as inert fillers, pigments, ethyl silicate, etc.

The purpose of treating a minor part of the MgO separately in a premix is to delay, or entirely prevent, the reaction of this minor part of the MgO with the MgCl<sub>2</sub>.6H<sub>2</sub>O during the main reaction and making it available later for a slow reaction with MgCl<sub>2</sub>. This not only permits control of the reaction from a process standpoint, such as reaction temperature, exothermic, pot life, viscosity and time of reaction, but results in a final cured product of improved strength, water resistance, and loss of material on dry-wet cycling.

The reaction of part of the MgO can be inhibited or delayed in various manners. For example, part of the MgO used to form the Sorel cement can be treated with phosphoric acid or a reactive phosphoric acid salt or compound and the premix allowed to stand until all of the phosphoric acid has been used up or reacted. The magnesium chloride can then be added together with the remainder of the MgO, inert fillers, pigments, etc. Part of the MgO can also be treated with or encased by an oil, such as linseed oil or silicone oil.

Other reaction inhibitors include water soluble silicates or sols, such as sodium stabilized silicates (silica) sols, lithium stabilized polysilicate, hydrolyzed silicates, low sodium polysilicates, such as water glass, siliconates and tin salts, such as stannous chloride. The lithium stabilized polysilicates have been found to be the most advantageous reaction inhibitor to date. In addition to the improved properties obtained with this polysilicate inhibitor, improved pot life is obtained since its addition does not cause the evolution of heat.

The addition of acid (preferably in concentrated form so as not to decrease significantly the specific gravity of the solution) appears to result in a more homogeneous cementing reaction. The resulting cement product is not only more weather resistant, but significantly stronger than acid-free magnesium oxychloride cements.

Moreover, the addition of concentrated acid tends to shorten the set time, thereby allowing the end user to control the set time. Concentrated hydrochloric acid and sulfuric acid are known to produce these results. It is believed other concentrated acids such as nitric acid and phosphoric acid may also be suitably added to the cement composition for certain applications of the present invention [19].

The phosphoric compounds that can be used are phosphoric acid and the water soluble phosphoric acid salts or compounds, such as ammonium phosphate, sodium phosphate and the like. The phosphorous compounds should have a sufficient acidity to react fairly rapidly with MgO. Phosphoric acid is preferred at present over its salts.

The amount of reaction inhibitor that can be used will depend upon the particular inhibitor selected and the degree of water resistance and strength desired in the final cured product. Reactive inhibitors, i.e., those that actually react chemically with MgO, such as phosphoric acid and its reactive salts, are treated somewhat differently with respect to the amounts to be used than the non-reactive type inhibitor, such as the silicates. The reactive inhibitors should not be used in any significant excess in the premix since the excess will also react with the MgO or the  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$  in the main mix and interfere with the curing as explained below.

The optimum amount of phosphoric acid (85%) found to date is about 5 percent by weight based on the MgO used to form the premix. The effect of amounts less than 5 percent has not been determined except that 0.2 to 0.5 percent by weight phosphoric acid appears to have little or no effect in improving the water resistance of the cured Sorel cement. The one limiting factor here is of a practical nature. If a high percentage of the MgO, e.g., 85% of total amount to be used, is employed in the premix with all of the external water, more phosphoric acid could be used but the mix becomes so viscous as to render adequate mixing of the other ingredients,  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ , fillers, etc., extremely difficult. Therefore, as a practical matter, the amount of MgO used in the premix is limited to that amount which will permit ease of blending the other ingredients in the premix.

Generally, when the MgO used in the premix is above 25% of the total MgO employed, the viscosity begins to rise and mixing problems begin. This practical limit on the amount of MgO that can be used in the premix with phosphoric acid thus places a practical limit on the amount of phosphoric acid that can be employed since it cannot be in any significant excess of that which will react with the MgO present. However, 5% by weight of phosphoric acid based on 25% by weight of the total MgO employed gives excellent results [21].

## **CHAPTER THREE**

### **Materials and Methods**

#### **3.1 Materials**

The following materials are used in this investigation:

**A. Magnesium Oxychloride Cement:** Magnesium Oxychloride Cement is not a product that is commercially available in the prepared form; it must be prepared on site from the raw materials. It is a hydraulic cement mixture of magnesium oxide (burnt magnesia) with magnesium chloride. In this research, the composition of magnesia cement is used shown in Table 3.1

Table 3.1 The composition of magnesia cement

Raw materials	Constituents
MgO: MgCl <sub>2</sub> solution	33:46 ratio
MgCl <sub>2</sub> solution	MgCl <sub>2</sub> .6H <sub>2</sub> O+water+ additives
Gauging solution: 22° Be* MgCl <sub>2</sub> .6H <sub>2</sub> O	40 % MgCl <sub>2</sub> .6H <sub>2</sub> O in water solution (Sp. gravity=1.179)

**Major Components  
of Magnesia  
Cement**

1. **Magnesium oxide:** Commercial grade magnesia (magnesium oxide) which produced locally used in the study having the following characteristics:

- (i) Bulk density =1060 Kg/m<sup>3</sup>,
- (ii) 90 % passing through 150µm,
- (iii) Magnesium oxide 87%.

2. **Magnesium chloride:** Imported Magnesium chloride(as MgCl<sub>2</sub>.6H<sub>2</sub>O)used with the following characteristics:

- (i) Bulk density =799 Kg/m<sup>3</sup>,
- (ii) Colorless, crystalline, hygroscopic crystals,
- (iii) Highly soluble in water,
- (iv) Magnesium chloride 98%.

\* Method of conversion ° Be (degree of Baume) to Sp. gravity and % by mass is given in

*Appendix B.*

**B. Fillers:** The fillers utilized in the tests are pumice, bagasses, saw dust and coffee husk. They dried in the ovens and had particle size in the range of all passing 450 $\mu$ m and all retained 300 $\mu$ m mesh size. The bulk density and absorption capacity is shown in Table 3.2.

The chloride solution absorbing capacity was determined by filling the pan the solution and letting fillers stand for 30 minutes. The data analyzed in ANOVA (Analysis Of Variance) method are given in APPENDIX A.

The chemical composition of pumice [from Metahara quarry site] is shown in Table 3.3.

Table 3.2 The physical characteristics of fillers tested in laboratory

<b>Filler type</b>	<b>Bulk density (kg/m<sup>3</sup>)</b>	<b>MgCl<sub>2</sub> solution absorption capacity (%)</b>
Bagasse	125 $\pm$ 2.6	119 $\pm$ 4
Sawdust	126 $\pm$ 0.6	126 $\pm$ 4
Coffee husk	348 $\pm$ 3.5	238 $\pm$ 3

of

Table 3.3 The chemical composition of pumice

<b>Component</b>	<b>Percent by mass</b>
SiO <sub>2</sub>	68.8

### **3.2 Mix Design**

Mix design is the process of selecting suitable ingredients of building materials and determining their relative quantities with in the purpose of producing an economic material which has certain minimum properties, notably workability, strength and durability.

It should be explained that design in the strict sense of the world is not possible: the material used are variables in a number of respect and many of their properties can not be assessed truly quantitatively. It is not surprising, therefore, that in order to obtain a satisfactory mix we must check the estimated proportions of the mix by making trial mixes, and if necessary, makes appropriate adjustment to the proportions until a satisfactory consistence mix has been obtained; otherwise, alternatively using previously consistency established relations for mixes compose from similar ingredients.

The mix design of the magnesium oxichloride and filler paste is adopted from the consistency of the Production Center mix proportion as a reference and determining of the working consistency based on British standard [22].

The working consistency was determined by means of the Vicat apparatus using the plunger 10mm in diameter to a magnesium oxychloride paste with fillers in the Vicat mould, the plunger comes to rest at a distance not exceeding 15mm from the bottom of the mold.

Based on the working consistency of Agrostone Production Center mix proportion paste (control paste), the workability and consistency of the other paste with different fillers and mix ratio were established.

### 3.3 Sample Preparation

Two types of test pieces were prepared with magnesia cement in constant mix ratio of magnesium oxide and magnesium chloride solution with the fillers based on Production Center process and relevant test method [22].

All mix was done in an open –pan type mixer of 20 liter capacity. The following mixing cycle was employed. The weighted mass of MgO powder and a measured volume of MgCl<sub>2</sub> solution were mixed, after which the weighted pumice powder and the estimated quantity of filler was added until a working consistency obtained. Trial mixes were made with varying percentage of fillers until the amount necessary for determine the consistency as defined above was found. The amount of filler used was recorded.

The mixed paste was filled the 70mm cube mould for the first test piece and on beams measuring 120×40×40 mm for the second test piece and consolidated with finger pressure only. Each mold rested horizontally on a non-porous plate, both the mould and the plate had previously been slightly greased with petroleum jelly. The mould should be cast immediately after the wet mix had attained the required consistency. The surf ace of the test piece finished smooth with the blade of a trowel or plate knife.

The molded materials keep them at  $27\pm 2^{\circ}\text{C}$  in an atmosphere of at least 90 percent relative humidity for 24 hours in humidity cabinet oven .They were then carefully removed them from the moulds and placed them in a tray. The tray then stored away from droughts in a room that maintained at a temperature of  $27\pm 2^{\circ}\text{C}$  and relative humidity of 65 to 70 percent.

The first board test pieces were prepared to determine the bulk density, oven dry density, water absorption test and compressive strength.

The second board test pieces manufactured for determination of bending strength.

The mix proportion of magnesia cement board is shown in Table 3.4. The first three specimens i.e. the CB, SMCB and CMCB have similar ratio of magnesium oxide, magnesium chloride solution and pumice powder with varying fillers mass. Where as the next specimens, that is, BMCB1, BMCB2 and BMCB3 have similar ratio of magnesia cement paste with varying pumice powder and bagasse.

Table 3.4 The mix proportion by mass of the magnesia cement boards for different fillers

Sample Designation	MgCl <sub>2</sub> Solution	MgO	Pumice	Bagasse	Saw dust	Coffee husk
CB (CONTROL)	200	144	65	27	---	---
PS	200	144	65	---	34	---
PC	200	144	65	---	---	66
PB1	200	144	43.5	30.3	---	---
PB2	200	144	20	32.5	---	---
PB3	200	144	---	35.3	---	---

### 3.4 Physical Properties

Bulk density, Water absorption test and oven dry densities were examined using the ASTM (American Society for Testing and Materials, 1999) [23]. The effect of fillers on setting characteristics of magnesia cement has been studied by incorporating it in mix proportion. Setting time of the wet mixes prepared with the gauging solution was determined adopting standard procedure [24];

### 3.5 Mechanical Properties

The compressive strength and bending strength were determined using a Combined Compression and Binding Test Plant ( ToniNORM Series, Quality and Standard Authority of Ethiopia). The mechanical strength tested using the Indian standard[25].

## CHAPTER FOUR

### Results and Discussions

#### 4.1 Results

##### 4.1.1 Physical Properties

The bulk density and oven dry density of the alternate building materials specimens shown in Table 4.1. ANOVA analyses of physical properties data are shown in APPENDIX A.

Table 4.1 Bulk density and oven dry density test result

Specimen Designations	Bulk density (kg/m <sup>3</sup> )	Oven dry density(kg/m <sup>3</sup> )
CB (CONTROL)	1014±1.5	969±6.6
PS	1064±2.5	992±8.0
PC	1143±4.2	1072±8.5
PB1	1011±4.2	925±10.3
PB2	966±5.7	874±12.2
PB3	883±12.2	837±12.2

The water absorption test result for a composite material of oven dried specimens is shown in Table 4.2. The dry oven specimen is a specimen obtained after drying a test piece at 103±2°C until constant weight is reached.

Table 4.2 Water absorption test result

Specimen Designations		Water absorption test (%)	
CB (CONTROL)		33.90±0.03	
PS		32.49±0.28	
PC		30.06±0.04	

Specimen Designations		Setting time	Setting time
		Initial (min)	Final (min)
	PB1	35.56 ± 0.03	
	PB2	40.69±0.04	
	PB3	43.53 ± 0.15	
CB (CONTROL)		86±1	177±1
PS		76±2	145±2
PC		58±2	133±1
PB1		92 ± 2	183±2
PB2		94±1	190±2
PB3		101±2	197±2

Setting time is one important factor

which determines the interaction of fillers with magnesia cement pastes. The time of set of the neat paste at normal consistency is determined by ability of the specimen of paste to sustain the weight of specified needles or small rods in Vicat apparatus.

The apparatus determined the initial set and final set. Initial set indicates the beginning of noticeable stiffening. Final set is taken to indicate beginning of what may be regarded as the hardening period in pastes. The initial and final setting time results are shown in Table 4.3.

Table 4.3. Initial and final setting time results of the magnesia cement paste.

### **4.1.2 Mechanical Properties**

The mechanical properties of the boards are measure of its resistance to exterior forces which tend to deform its mass. The resistance of board to such forces depends on their magnitude and manner of loading (compression, bending, tension, shear, etc).

The compressive strength and the bending strength results are shown in Table 4.4 and Table 4.5, respectively. The specimens were tested for mechanical strength at 7 and 28 days respectively after gauging with magnesium chloride solution, three specimens for each test, as per Indian standard test method [23]. ANOVA analysis of mechanical properties data are shown in APPENDIX A.

Table 4.4 Compressive strength test results

<b>Specimen designations</b>	<b>Compressive strength(Mpa) 7 Days</b>	<b>Compressive strength(Mpa) 28 Days</b>
CB (CONTROL)	8.77±0.22	14.33± 0.25
PS	10.90±0.36	17.37 ± 0.21
PC	14.24±0.48	18.03 ± 0.15
PB1	8.32±0.20	12.23 ± 0.47
PB2	8.18±0.14	11.20 ± 0.10
PB3	7.32±0.15	8.58 ±0.54

Table 4.5 Bending strength test results

## 4.2 Discussion

<b>Sample designations</b>	<b>Bending strength(Mpa) 7 Days</b>	<b>Bending strength(Mpa) 28 Days</b>
CB (CONTROL)	3.50±0.03	4.35± 0.45
PS	4.12±0.02	4.92± 0.08
PC	3.83 ±0.03	5.24 ± 0.34
PB1	3.36± 0.04	4.00 ± 0.44
PB2	3.09±0.07 57	4.09 ± 0.07
PB3	2.62±0.03	3.50 ± 0.10

Based on the mix proportion of fillers ,the board test pieces are divided into two cases, the first case includes the PB, and PS and PC .The second cases

includes PB1, PB2 and PB3.

**CASE ONE:** the first three specimens, the pumice bagasse board (control board), the sawdust pumice board (PS) and the coffee husk pumice board (PC) are the boards made from constant magnesia cement ratio and different proportion of agro fibers as show in Table 3.4. The fillers have different mix proportions due to they have different density and magnesium chloride solution absorbing capacity as shown in Table 3.2. The filler with higher density and absorbing capacity like coffee husk have more consumes in production of boards and results in dense board than the other boards as shown in Figure 4.1.

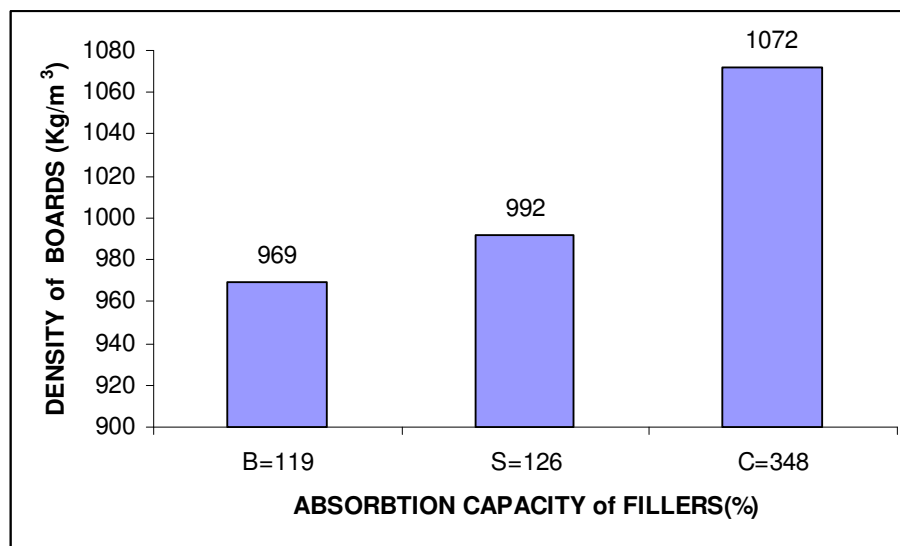


Figure 4.1 The effect of absorption capacity of fillers on the density of magnesia cements boards

In Table 4.2, the water absorption test for oven dried specimen carried out to compare boards' nature in the different filler for water resistance. The higher the (%) of water absorptions is, the lower the water resistance property of the materials. The highest percentage of water absorption is observed in bagasse boards (control board), which means it is less reactive to admixture chemicals which help to impart the fiber hydrophobicity. The test shows that coffee husk board is the least water absorbed material.

When the oven dry density of the board show as a function of the water absorptions of the dried specimen as in Figure 4.2, the least dense board, control board which has poor water resistance whereas the dense board, the coffee husk board, has good water resistance

property. This shows the water resistance of boards is related to the characteristics of fillers, the interaction of filler components with binder and admixtures, and the density of boards.

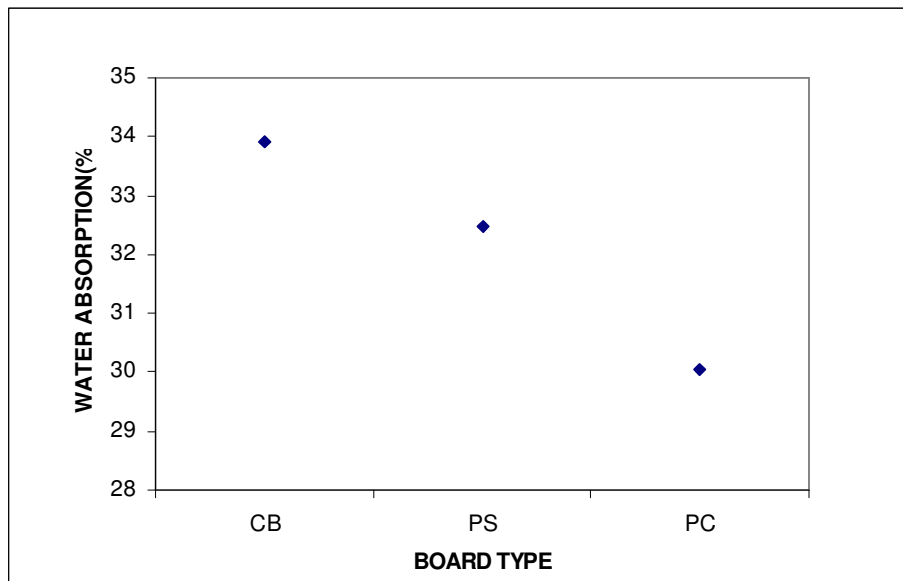


Figure 4.2 Water absorption of magnesia cement boards

The water resistance of sawdust board is better than the bagasse boards (control board). From literature, both are composed of cellulose, lignin, hemicellulose and others. However, the presence of hemicellulose is higher for bagasse than the sawdust. Hence, the higher percentage of hemicellulose results for higher water absorbance character of the lignocellulostic material [26]. As a result the bagasse boards' resistance to water may be low compared to saw dust board. The fiber content of the coffee husk is lower than bagasse and saw dusts, this may result in low water absorbance character [27].

The setting time of the magnesia cement paste with different agro fillers shown in Table 4.3. The setting time of the paste are affected by the composition of paste and nature of fillers. As already mentioned in literature review lignocellulostic fillers has retarding property on setting of pastes. This can be understood by comparing with magnesia cement with pumice filler paste.

The setting of magnesia cement is the result of a series of chemical reactions causing a succession of crystallization stages. Crystallizations are inhibited to a varying degree by various materials and their extractives. In our case, the coffee husk filler board has relatively lower setting time than others boards. So this may be it have less extractive and resinous matter which retard the set time.

The bagasse which may have higher sugar content than other fillers can cause retardation of the hydration of the cement. The extractable components in saw dusts have a retarding effect on the setting of magnesia cement .However, the magnesia cement has fast setting cement than Portland cement and gypsum cement, the effects is less compare to this cement. The setting time is related to the area of production which means at relatively cold area rapid setting cement like PC is needed where as in hot area a slow setting cement paste is needed.

The mechanical properties of fiber cement board are affected by such factors as board density, kind of furnish (fine fibers, fiber bundles), the binder, additives and others. In Table 4.4, the compressive strength of the fillers is shown. When comparing its relation with density in a Figure 4.3, the highest compressive strength observed in a pumice board i.e. the dense board, whereas the least compressive strength is observed in the control board, which is the least dense board.

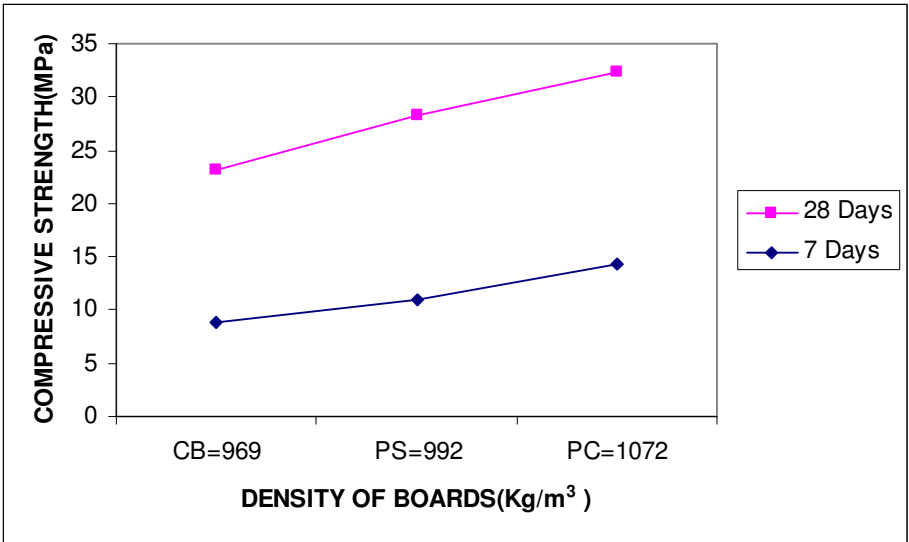


Figure 4.3 Compressive strength of the magnesia board as a function of density

Generally, the Figure 4.3 shows that as the density of the composite boards increases, the compressive strength also increase from control board to coffee husk board. This shows there is strong relationship between compressive strength and density.

The result is shown for bending strength. The coffee husk board is the highest and the least for control board. The sawdust board is slight stronger than the bagasse board. This may relate to the interaction among their packing fibers, and shear strength, internal bond and density.

The bending strength of the board as a function of board type is shown in Figure 4.4.

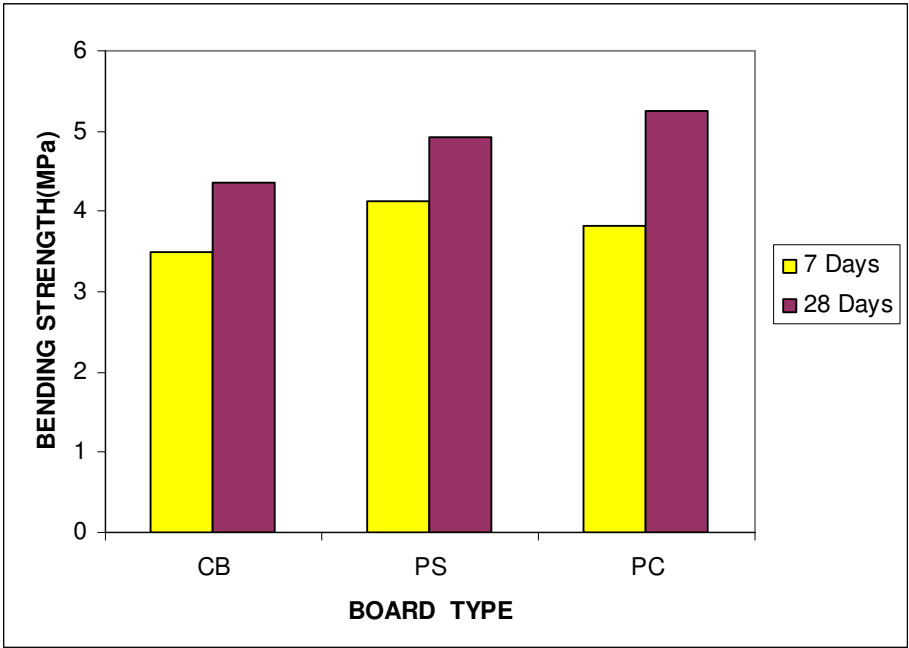


Figure 4.4 Bending strength of the different fillers boards

In contrast to bagasse boards (control board), the bending strength of woody materials is high. As a result, the sawdust board has good character of having a low bending property.

**CASE TWO:** for the second case, it includes the pumice bagasse boards of different mix proportion of pumice and bagasse powders. They are designated by PB1, PB2 and PB3. It includes CB which is also composed of pumice and bagasse filler and has higher proportion of pumice and lower proportion of bagasse than PB1, PB2 and PB3.

The mix proportions are required to analysis the effect of pumice powder in the physical and mechanical property of the board.

For the case of water absorption of the boards, PB1boards has good resistance to water. This board type is the denser and having more pumice powder proportion than others. The BP3 produced only bagasse powder. It has poor resistance to water. This shows the nature of bagasse and pumice more influential factor to its water resistance. This is due to the nature of pumice, that is, the interaction of pumice fillers with the binder makes better resistance to water than bagasse filler. This is shown in Figure 4.5, where the effect of pumice filler is observed.

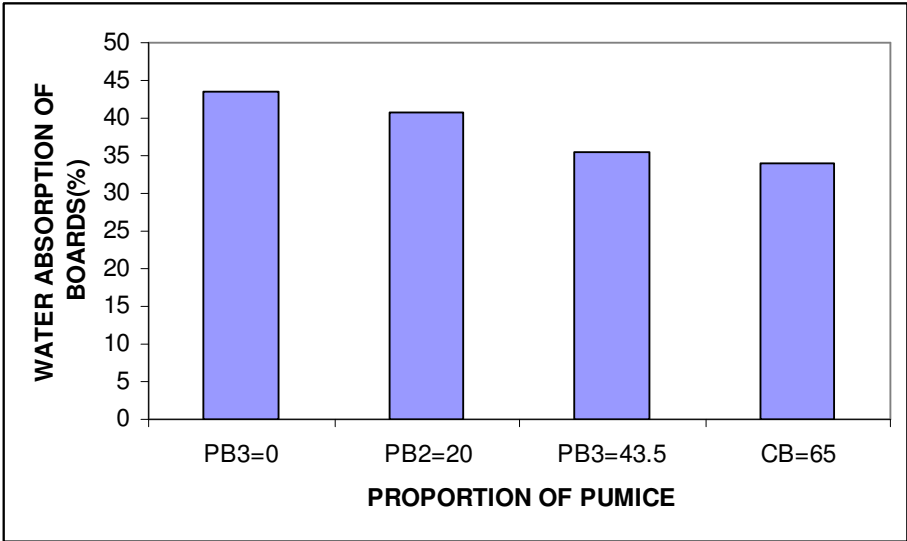


Figure 4.5 Water absorption of magnesia cement board as a function of pumice proportions

In the case of setting time, as the proportion of the pumice powder increases, the setting time reduces. The pumice powder has an alumina ( $Al_2O_3$ ) component that can speed up both the heat of hydration and the early strength [28]. The magnesia cement paste with the pumice fillers has  $49 \pm 1$  min and  $157 \pm 2$  min initial setting time and final setting time, respectively as shown in APPENDIX A.

As shown in Table 4.3, all fillers have higher set time than the pumice filler paste As a result; the pumice reduces the setting time of cement and the retarding effect of agro fillers components. This was observed in PB1 which has relatively low setting time. Where as PB3 is high setting time as shown in Figure 4.6

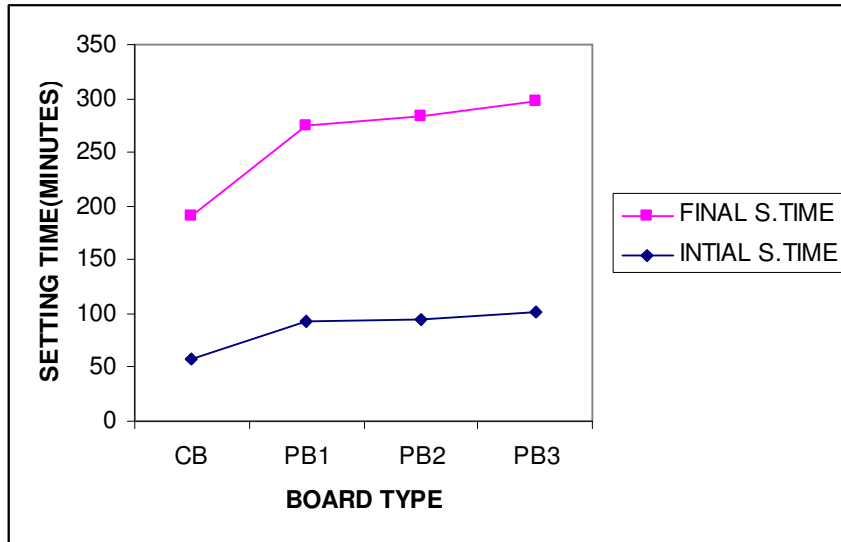


Figure 4.6 Setting time of pumice bagasse boards

For the compression strength of the pumice bagasse boards, the PB1 has high compressive strength and PB3 has low compressive strength as shown in Figure 4.7 that shows the bending and compressive strength of the 28 day produced board samples.

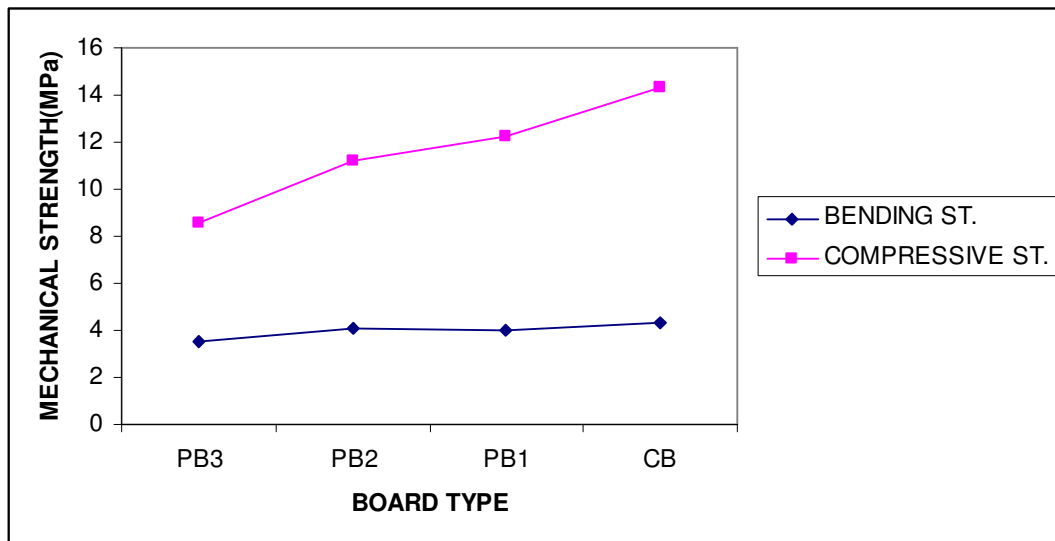


Figure 4.7 Compressive and bending strength of the pumice bagasse boards

From literature, Organic content of the material decreases the compressive strength [28]. So the high organic material content in bagasse lowers the compressive strength of the boards than the pumice magnesia cement boards (PB1 and PB2). This effect also observed in bending strength. Thus the PB3 has also low bending strength. The Control board (CB) which has high proportion of pumice has low water absorptions, fast setting and high mechanical strength compared to PB boards.

Generally, the utilization of excess pumice improves the impermeability and strength of the board. Its drawback is it raises the weight of the boards as shown in Table 4.1

## CHAPTER FIVE

### Benefits and Cost Analysis of Filler Boards

#### 5.1 Benefits of Filler Boards

The benefits of Agrostone products are:

- The widely available lightweight mineral fillers and agricultural wastes are the main input raw materials;
- Unlike to bricks and hollow concrete blocks (HCB) the partition boards don't require plastering for finishing surfaces;
- The surface area of this product is very large (1.5m<sup>2</sup>) when compared with brick/block. In other words it requires about 15 HCB to cover similar area of partition boards. This makes it easy to cover large area in short period of time that in turn reduces time required for construction;
- Since the density of the material is small, the weight of superstructure is reduced. This implies that the cost of substructure construction can be reduced;
- Unlike brick/block construction, the material does not require much water during construction. Therefore, the water used for construction can be saved suggesting a shift from wet to dry construction technology.

#### 5.2 Production Cost

Calculation on the production cost of Agrostone products has considered various variables. Production cost is generally divided into the categories of manufacturing cost and general expense.

The manufacturing costs are divided into two main groups as follows:

1. **Variable operating costs:** it includes expenses directly associated with the manufacturing operations and they are dependent on the amount of product produced.

The variable operating costs are:

- Raw materials,
- utilities ,

- miscellaneous operating materials ,etc.

Based on the definition of the variable operating cost, the raw material cost of each filler board is shown in Table 5.1, 5.2 and 5.3. The components in the raw material tables show the standard weight requirement of the constituents of the boards with price. The basic raw materials of magnesium oxychloride cement are locally produced magnesium oxide and imported magnesium chloride.

Table 5.1 Raw material cost of bagasse filler board (control board) [August 2007]

Description	Consumption Quantity/board(Kg)	Unit price (Birr/Kg)	Birr per board	Birr per m <sup>2</sup>
Magnesium Oxide (MgO)	18	1.75	31.50	21.00
Magnesium Chloride (MgCl <sub>2</sub> )	12.51	2.00	25.02	16.68
Fiberglass	1.01	8.00	8.08	5.39
Pumice	8.33	0.15	1.25	0.83
Bagasse	3.03	0.75	2.27	1.52
Steel bar (4mm)	0.11	24.00	2.64	1.76
Admixtures	0.12	16.34	1.96	1.31
Additional materials				
• Advertising cloth		5.40 Birr/m	1.89	1.26
• Lubricating oil		21Birr/liter	1.05	0.70
• Rubber mat		500 Birr/m <sup>2</sup>	1.50	1.00
Total	43.11		75.10	51.44

Table 5.2

Raw material cost of saw dust filler board [August 2007]

Description	Consumption Quantity/board(Kg)	Unit price (Birr/Kg)	Birr per board	Birr per m <sup>2</sup>
Magnesium Oxide (MgO)	18	1.75	31.50	21.00
Magnesium Chloride (MgCl <sub>2</sub> )	12.51	2.00	25.02	16.68
Fiberglass	1.01	8	8.08	5.39
Pumice	8.33	0.15	1.25	0.83
saw dust	3.92	0.35	1.37	1.52
Steel bar (4mm)	0.11	24.00	2.64	1.76
Admixtures	0.12	16.34	1.96	1.31
Additional materials				
• Advertising cloth		5.40 Birr/m	1.89	1.26
• Lubricating oil		21Birr/liter	1.05	0.70
• Rubber mat		500 Birr/m <sup>2</sup>	1.50	1.00
Total	44.00		76.26	50.84

Table 5.3 Raw material cost of coffee husk filler board [August 2007]

Description	Consumption Quantity/board(Kg)	Unit price (Birr/Kg)	Birr per board	Birr per m <sup>2</sup>
Magnesium Oxide (MgO)	18	1.75	31.5	21.00
Magnesium Chloride (MgCl <sub>2</sub> )	12.51	2.00	25.02	16.68
Fiberglass	1.01	8.00	8.08	5.39
Pumice	8.33	0.15	1.25	0.83
Coffee husk	7.68	0.70	5.38	1.52
Steel bar (4mm)	0.11	24.00	2.64	1.76
Admixtures	0.12	16.34	1.96	1.31
Additional materials				
• Advertising cloth		5.40 Birr/m	1.89	1.26
• Lubricating oil		21Birr/liter	1.05	0.70
• Rubber mat		500Birr/m <sup>2</sup>	1.50	1.00
Total	47.76		80.27	53.51

2. Fix

**ed operating costs:** they are expenses which are practically constant from year to year and do not vary widely with changes in production rates. These are the bills that have to be paid whatever the quantity of the product produced.

The items of the fixed operating costs are:

- operating labor,
- laboratory cost,
- supervision,
- plant overhead,
- depreciation,
- local taxes

The components of the fixed cost are given in Table 5.4

General expense: besides fixed and variable manufacturing costs, other general expenses are involved in any company operations. These general expenses are administrative expense, distribution and gross earning expenses [30].

The production center provides the partition board to the Addis Ababa Housing Development Project Office, it does not sell its product to the market, and hence, it assumes negligible costs for general expense. The production cost of the board is shown in Table 5.4.

Table 5.4 Production cost of the different filler boards [August 2007]

No.	Description	Cost (Birr/m <sup>2</sup> ) Bagasse board	Cost (Birr/m <sup>2</sup> ) Sawdust board	Cost (Birr/m <sup>2</sup> ) Coffee husk board
1	Operating labors	4.16	4.16	4.16
	A/ Laborers	3.54	3.54	3.54
	Technical staff	3.59	3.59	3.59
	Subtotal	11.29	11.29	11.29
2	Raw material cost	51.44	50.84	53.51
3	Utility cost	0.62	0.62	0.62
4	Machinery depreciation	0.47	0.47	0.47
5	Building depreciation	0.45	0.45	0.45
	Sub total	64.27	63.67	66.34
	Overhead cost (5%)	3.21	3.18	3.32
	Production cost	67.48	66.85	69.66

### 5.3 Cost Comparison

If the sawdust substitutes the bagasse filler, the weight of the board increases with 2% but the production cost of board decreases with due to the cheapness of sawdust than bagasse filler.

Similarly, if the coffee husk substitutes the bagasse filler, the weight of the board increases with 9.7 % and the production cost rises with 3.1 %. Both fillers relatively have equal price, however the proportion of bagasse is lower than coffee husks results in reduction of raw material cost.

The main limitation of saw dust filler is availability, which means that bagasse filler is available in large amount as a sugar factory byproduct than saw dust. Where as coffee husk has no scarcity as Ethiopia is a major coffee producing country.

While comparing cost of the filler boards with the commonly used hollow concrete blocks, which includes cost for fitting and finish works, shown in Table 5.5.

Table 5.5 Cost comparisons of hollow concrete blocks and filler boards [August 2007]

Description	Hollow concrete blocks		Filler board bagasse	Filler board Saw dust	Filler board Coffee husk
	20cm	15cm	10cm	10cm	10cm
Type	20cm	15cm	10cm	10cm	10cm
Product Cost (Birr/m <sup>2</sup> )	53.64	48.42	67.48	66.85	69.66
Mortar/chemical for fitting	14.82	7.56	2.45	2.45	2.45
Labor cost for fitting	10.11	7.26	7.19	7.19	7.19
Sub total	78.57	63.24	77.12	76.49	79.30
Finishing work					
Mortar for plastering/varnish	20.28	20.28	---	---	---
Labor cost painting	20.00	20.00	---	---	---
Sub total	55.28	55.28	15.00	15.00	15.00
Grand total	<b>133.85</b>	<b>118.52</b>	<b>107.10</b>	<b>106.49</b>	<b>109.30</b>

In targeting of production of alternative building materials with low cost, the Table shows the possibility of producing with finish work relatively lower price than hollow concrete blocks.

Although the product cost of the hollow concrete blocks (HCB) lower than boards, the fiber boards is no need of plastering and block work results in reduction of production cost. For instance, it costs 60-65 % of total cost of HCB; where as in filler boards it costs only about 23 % of total cost.

## **CHAPTER SIX**

## Conclusions and Recommendations

In aim of production of alternative building materials using different fillers, the following conclusions were obtained.

The magnesium chloride solution absorbing capacity of fillers has impact on the proportion of fillers on the production of board samples. As the proportion of lignocellulostic fillers increases, the density and weight of the board produced increased.

The density of the fillers and density of boards are also interrelated each other. Hence using dense fillers produced dense cement board.

From the discussions, the water absorption of the bagasse cement board is higher compare to others. Since coffee husk and bagasse boards have a good water resistance property. So they can substitute or an alternative material for bagasse filler board (control board).

The setting time of the bagasse cement paste is high than others. It can be reduced by increasing the proportion of pumice.

For the case of compressive strength and bending strength of the boards, which is related to the density and nature of raw materials, as a result a coffee husk board shows a better result to others. The control board shows the least.

The mix ratio of fillers and pumice powder has also influence on the physical and mechanical property of the boards. As the proportion of lignocellulostic filler increases, the water permeability and setting time increases. However, the bending strength and compressive strength are reduced. The nature and character of pumice which constitutes high percentage of inorganic materials in board production enhance low water permeability and the mechanical strength. As a result, as the proportion of pumice increases in paste, the density and the mechanical strength of the board increase.

The cost analysis of filler boards shows, the product cost of saw dust boards is relatively lower than other boards.

In aim of production of alternative building materials using the fillers are, the project result in the possibility of producing relatively low price than the hollow concrete blocks that includes cost of finish work.

Generally, the substitution of saw dust and coffee husk with bagasse filler in producing boards result in better physical and mechanical property than the control board. Its drawback is it is slightly not light weight as bagasse boards.

The need for utilization of local materials such as coffee husk and sawdust serves as cost effective and offer a potential market in construction sector. The boards are not depend on Portland cement and help to fill the gap in the demand of construction materials.

**I recommend the following points:**

The current used magnesia cement has corroding the metals. So it is better minimize its corrodeness by adding additives such as including sodium metasilicate, zinc sulfate and aluminum sulfate [31].

The fire resistively, sound insulation and modules of elasticity of the boards with different fillers are important parameter for utilization of the boards in construction. So I suggest further research be done on these properties.

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# APPENDIXES

## APPENDIX A

### ANOVA METHOD OF DATA ANALYSIS OF TEST RESULTS

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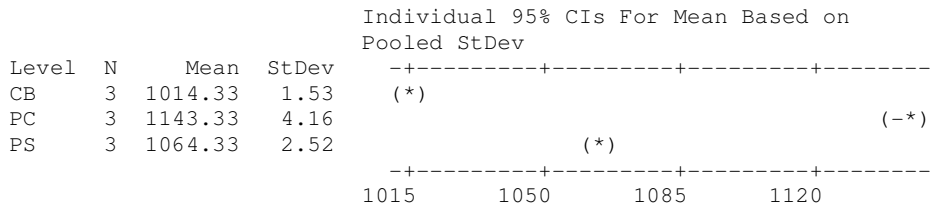
Welcome to Minitab, press F1 for help.

#### A.Data analysis of Bulk Density

#### One-way ANOVA: Bulk density versus B-Type (Board type CB, PC & PS)

Source	DF	SS	MS	F	P
B-Type	2	25382.00	12691.00	1464.35	0.000
Error	6	52.00	8.67		
Total	8	25434.00			

S = 2.944 R-Sq = 99.80% R-Sq(adj) = 99.73%

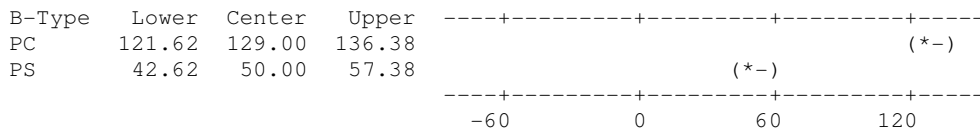


Pooled StDev = 2.94

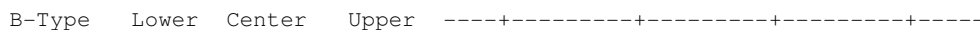
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

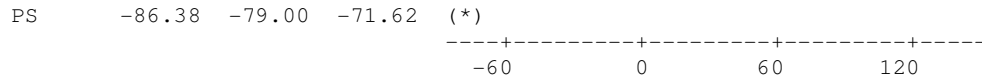
Individual confidence level = 97.80%

B-Type = PB subtracted from:



B-Type = PC subtracted from:

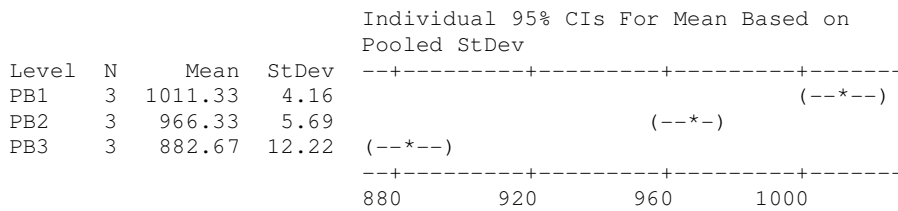




**One-way ANOVA: Bulk Density versus Board type (PB1, PB2 & PB3)**

Source	DF	SS	MS	F	P
B-Type	2	25580.2	12790.1	192.82	0.000
Error	6	398.0	66.3		
Total	8	25978.2			

S = 8.145    R-Sq = 98.47%    R-Sq(adj) = 97.96%

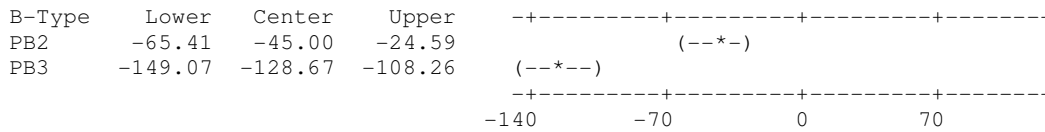


Pooled StDev = 8.14

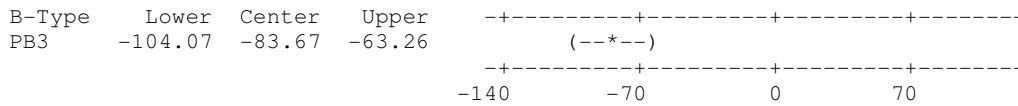
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = PB1 subtracted from:



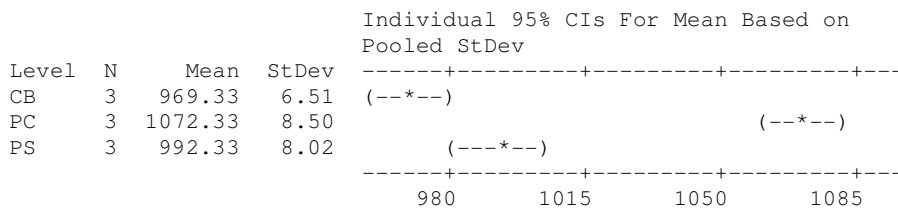
B-Type = PB2 subtracted from:



**B.DATA ANALYSIS OF DENSITY**  
**One-way ANOVA: Density versus Board type (CB, PC & PS)**

Source	DF	SS	MS	F	P
B-Type	2	17538.0	8769.0	146.97	0.000
Error	6	358.0	59.7		
Total	8	17896.0			

S = 7.724    R-Sq = 98.00%    R-Sq(adj) = 97.33%

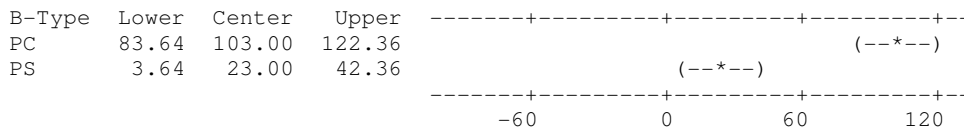


Pooled StDev = 7.72

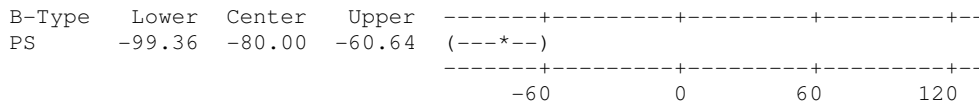
Tukey 95% Simultaneous Confidence Intervals  
 All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = CB subtracted from:



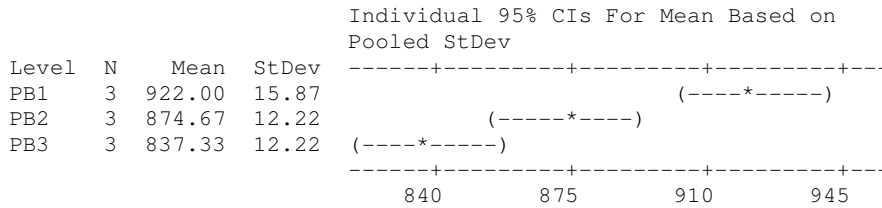
B-Type = PC subtracted from:



**One-way ANOVA: Density versus Board type (PB1, PB2 & PB3)**

Source	DF	SS	MS	F	P
B-Type	2	10803	5401	29.43	0.001
Error	6	1101	184		
Total	8	11904			

S = 13.55    R-Sq = 90.75%    R-Sq(adj) = 87.66%

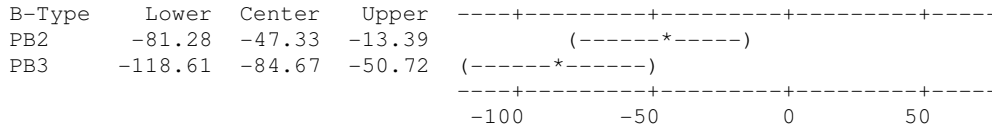


Pooled StDev = 13.55

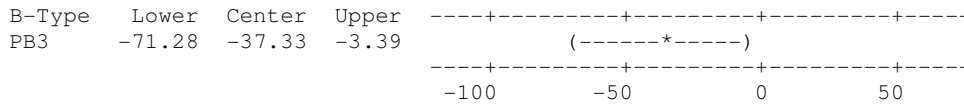
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = PB1 subtracted from:



B-Type = PB2 subtracted from:

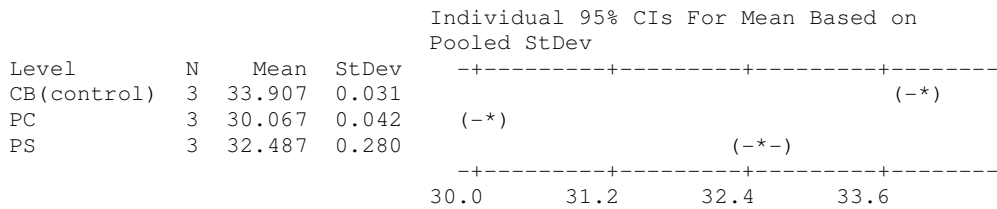


### C. DATA ANALYSIS OF WATER ABSORPTION

#### One-way ANOVA: Water absorption versus Board type (CB, PC &PS)

Source	DF	SS	MS	F	P
B-type	2	22.6184	11.3092	417.83	0.000
Error	6	0.1624	0.0271		
Total	8	22.7808			

S = 0.1645    R-Sq = 99.29%    R-Sq(adj) = 99.05%

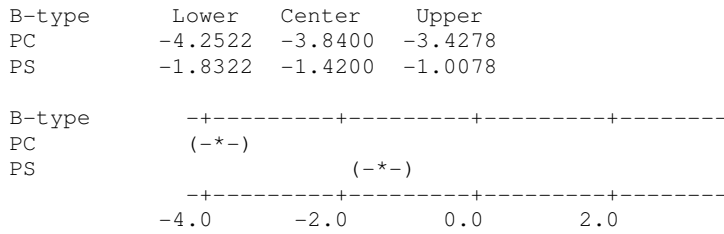


Pooled StDev = 0.165

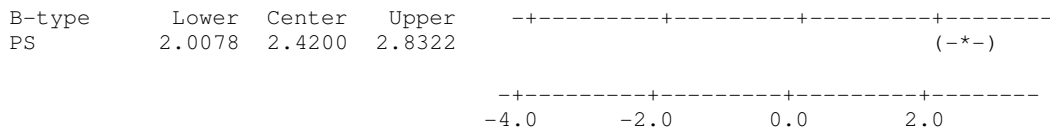
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-type

Individual confidence level = 97.80%

B-type = CB(control) subtracted from:



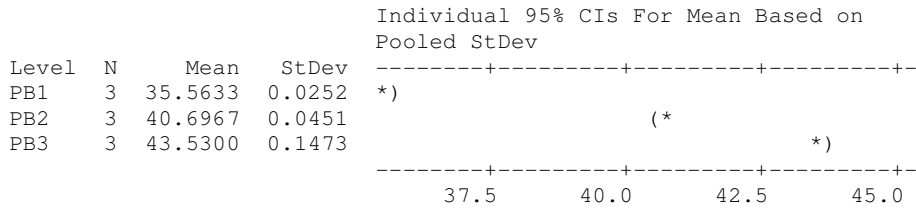
B-type = PC subtracted from:



**One-way ANOVA: Water absorption versus Board type (PB1, PB2 &PB3)**

Source	DF	SS	MS	F	P
B-type	2	97.84667	48.92333	6023.39	0.000
Error	6	0.04873	0.00812		
Total	8	97.89540			

S = 0.09012 R-Sq = 99.95% R-Sq(adj) = 99.93%

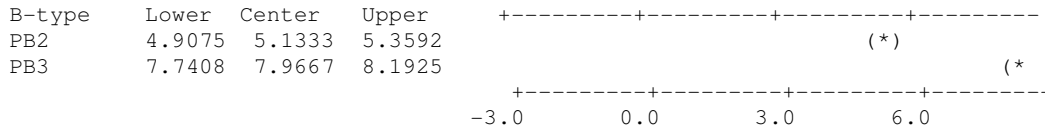


Pooled StDev = 0.0901

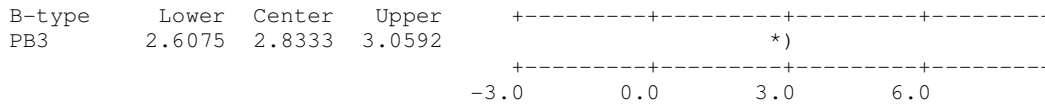
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-type

Individual confidence level = 97.80%

B-type = PB1 subtracted from:



B-type = PB2 subtracted from:

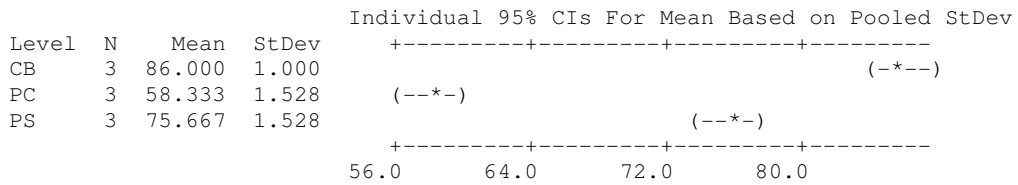


## D.DATA ANALYSIS OF INTIAL SETTING TIME

### One-way ANOVA: Initial setting (min) versus Board type (CB, PC & PS)

Source	DF	SS	MS	F	P
B-Type	2	1172.67	586.33	310.41	0.000
Error	6	11.33	1.89		
Total	8	1184.00			

S = 1.374    R-Sq = 99.04%    R-Sq(adj) = 98.72%

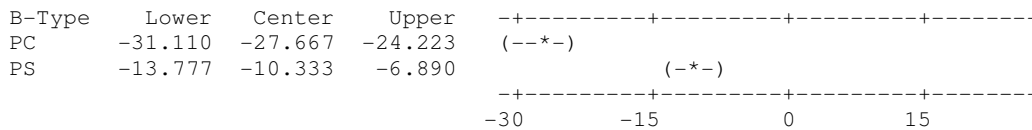


Pooled StDev = 1.374

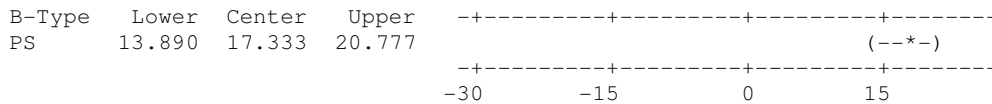
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = CB subtracted from:



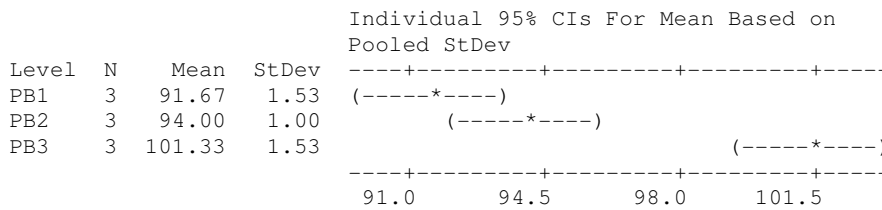
B-Type = PC subtracted from:



**One-way ANOVA: initial setting (min) versus Board type (PB1, PB2 & PB3)**

Source	DF	SS	MS	F	P
B-Type	2	152.67	76.33	40.41	0.000
Error	6	11.33	1.89		
Total	8	164.00			

S = 1.374 R-Sq = 93.09% R-Sq(adj) = 90.79%

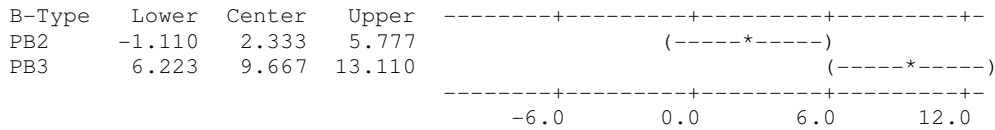


Pooled StDev = 1.37

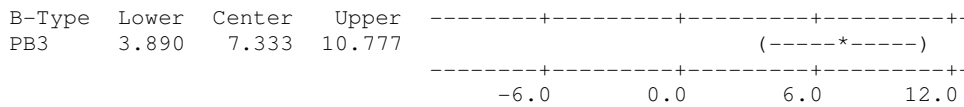
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

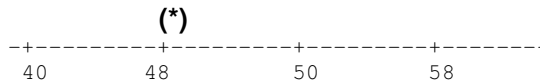
B-Type = PB1 subtracted from:



B-Type = PB2 subtracted from:



B-Type	mean	StDev
Pumice board	48.67	0.577

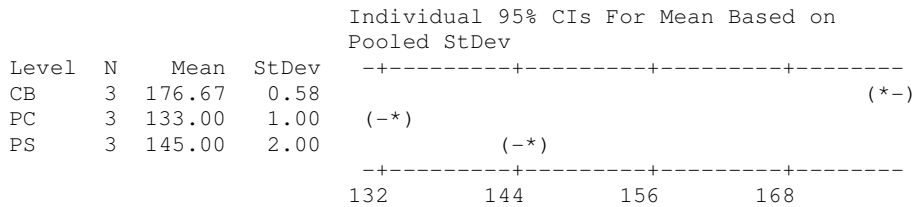


## E.DATA ANALYSIS OF FINAL SETTING TIME

### One-way ANOVA: Final setting (min) versus Board type (CB, PC & PS)

Source	DF	SS	MS	F	P
B-Type	2	3053.56	1526.78	858.81	0.000
Error	6	10.67	1.78		
Total	8	3064.22			

S = 1.333    R-Sq = 99.65%    R-Sq(adj) = 99.54%

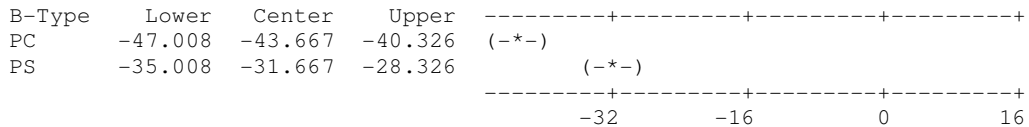


Pooled StDev = 1.33

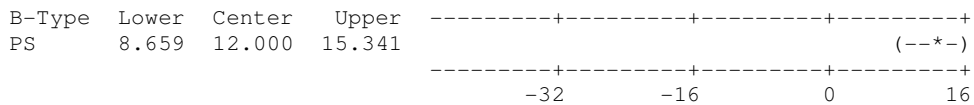
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = CB subtracted from:



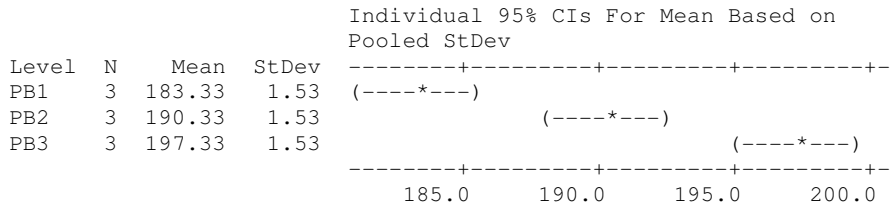
B-Type = PC subtracted from:



**One-way ANOVA: final setting (min) versus Board type (PB1, PB2 & PB3)**

Source	DF	SS	MS	F	P
B-Type	2	294.00	147.00	63.00	0.000
Error	6	14.00	2.33		
Total	8	308.00			

S = 1.528    R-Sq = 95.45%    R-Sq(adj) = 93.94%

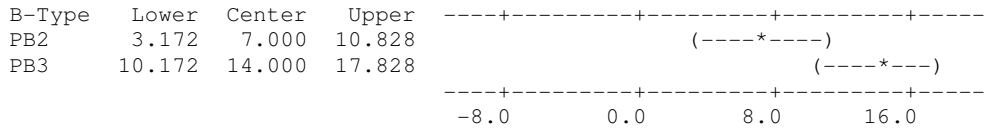


Pooled StDev = 1.53

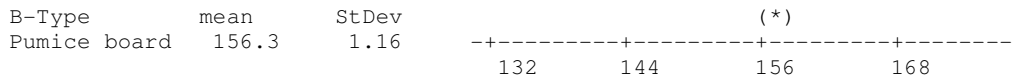
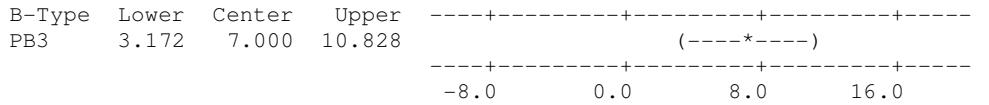
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = PB1 subtracted from:



B-Type = PB2 subtracted from:



## F.DATA ANALYSIS OF COMPRESSIVE STRENGTH

### One-way ANOVA: Compressive strength (7day) versus Board type (CB, PS & PC)

Source	DF	SS	MS	F	P
B-Type	2	45.613	22.807	167.25	0.000
Error	6	0.818	0.136		
Total	8	46.432			

S = 0.3693    R-Sq = 98.24%    R-Sq(adj) = 97.65%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev	CI
CB	3	8.770	0.221	(--*-)
PC	3	14.240	0.480	(-*--)
PS	3	10.900	0.361	(--*-)

-----+-----+-----+-----+-----+  
 10.0      12.0      14.0      16.0

Pooled StDev = 0.369

Tukey 95% Simultaneous Confidence Intervals  
 All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = CB subtracted from:

B-Type	Lower	Center	Upper	CI
PC	4.5447	5.4700	6.3953	(--*--)
PS	1.2047	2.1300	3.0553	(--*--)

-----+-----+-----+-----+-----+  
 -3.0      0.0      3.0      6.0

B-Type = PC subtracted from:

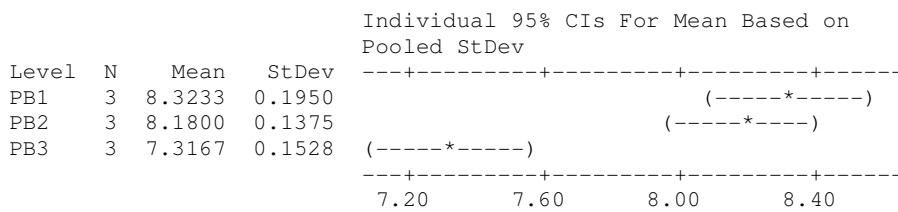
B-Type	Lower	Center	Upper	CI
PS	-4.2653	-3.3400	-2.4147	(--*--)

-----+-----+-----+-----+-----+  
 -3.0      0.0      3.0      6.0

**One-way ANOVA: Compressive strength (7day) versus Board Type (PB1, PB2 &PB3)**

Source	DF	SS	MS	F	P
B-Type	2	1.7793	0.8896	33.25	0.001
Error	6	0.1605	0.0268		
Total	8	1.9398			

S = 0.1636    R-Sq = 91.72%    R-Sq(adj) = 88.97%

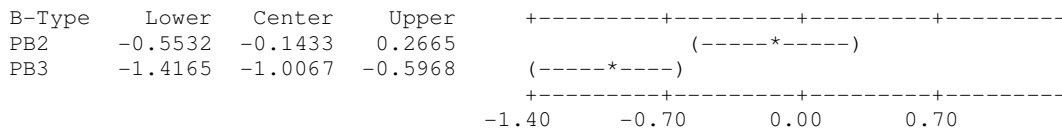


Pooled StDev = 0.1636

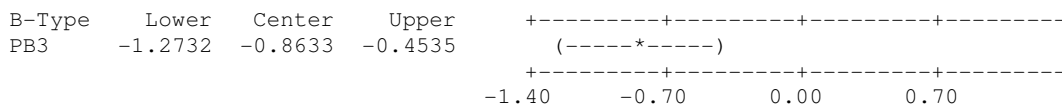
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = PB1 subtracted from:



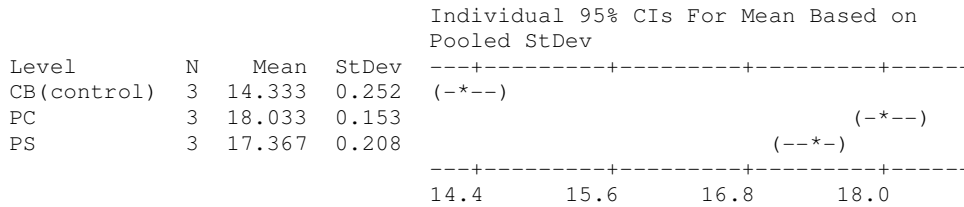
B-Type = PB2 subtracted from:



**One-way ANOVA: Compressive strength (28 days) versus board type (CB, PC &PS)**

Source	DF	SS	MS	F	P
B-type	2	23.3356	11.6678	269.26	0.000
Error	6	0.2600	0.0433		
Total	8	23.5956			

S = 0.2082    R-Sq = 98.90%    R-Sq(adj) = 98.53%

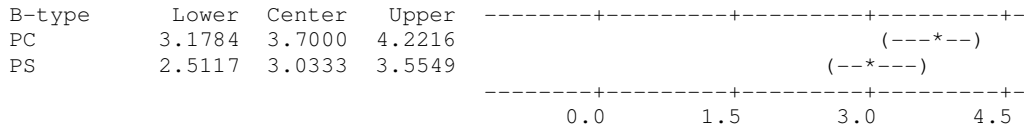


Pooled StDev = 0.208

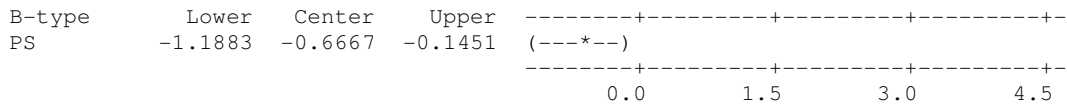
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-type

Individual confidence level = 97.80%

B-type = CB(control) subtracted from:



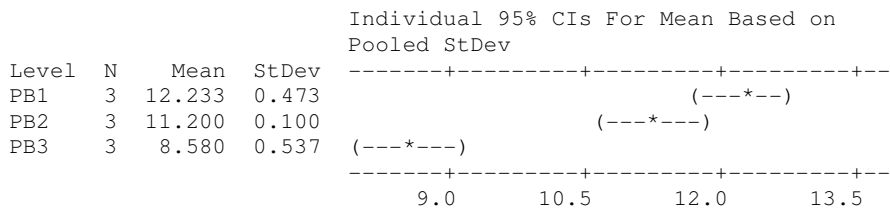
B-type = PC subtracted from:



**One-way ANOVA: Compression strength (28 days) versus Board type (PB1, PB2 & PB3)**

Source	DF	SS	MS	F	P
B-type	2	21.279	10.640	61.18	0.000
Error	6	1.043	0.174		
Total	8	22.322			

S = 0.4170    R-Sq = 95.33%    R-Sq(adj) = 93.77%

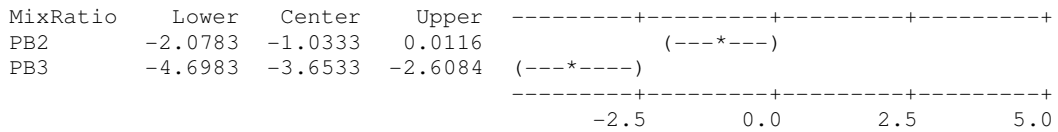


Pooled StDev = 0.417

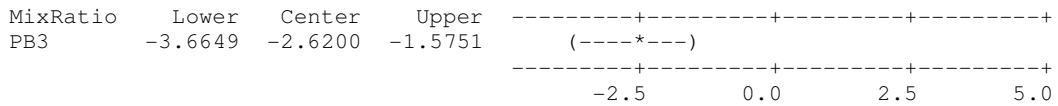
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-type

Individual confidence level = 97.80%

MixRatio = PB1 subtracted from:



MixRatio = PB2 subtracted from:

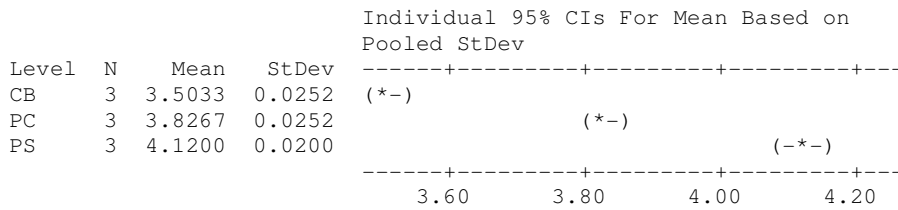


## G. DATA ANALYSIS OF BENDING STRENGTH

### One-way ANOVA: Bending strength (7day) versus Board type (CB, PC & PS))

Source	DF	SS	MS	F	P
B-Type	2	0.570867	0.285433	513.78	0.000
Error	6	0.003333	0.000556		
Total	8	0.574200			

S = 0.02357 R-Sq = 99.42% R-Sq(adj) = 99.23%

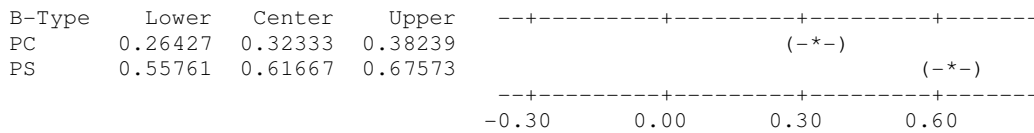


Pooled StDev = 0.0236

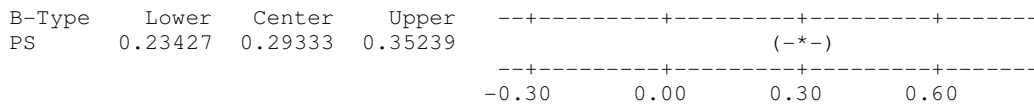
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = CB subtracted from:



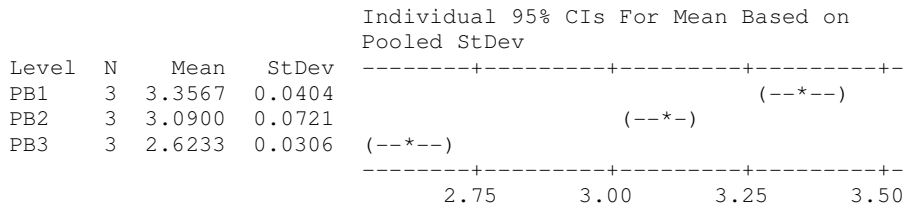
B-Type = PC subtracted from:



**One-way ANOVA: Bending strength (7day) versus Board type (PB1, PB2 &PB3)**

Source	DF	SS	MS	F	P
B-Type	2	0.82667	0.41333	159.66	0.000
Error	6	0.01553	0.00259		
Total	8	0.84220			

S = 0.05088 R-Sq = 98.16% R-Sq(adj) = 97.54%

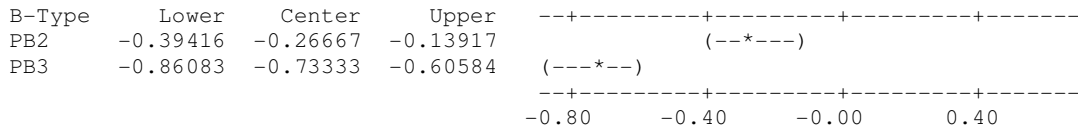


Pooled StDev = 0.0509

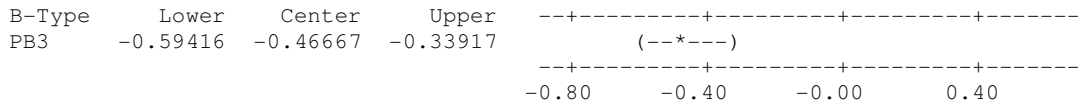
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-Type

Individual confidence level = 97.80%

B-Type = PB1 subtracted from:



B-Type = PB2 subtracted from:



**One-way ANOVA: Bending strength (28 days) versus Board type (CB, PC& PS)**

Source	DF	SS	MS	F	P
B-type	2	1.218	0.609	5.65	0.042
Error	6	0.647	0.108		
Total	8	1.864			

S = 0.3283    R-Sq = 65.32%    R-Sq(adj) = 53.75%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev
CB (control)	3	4.3500	0.4498
PC	3	5.2400	0.3378
PS	3	4.9167	0.0833

4.00      4.50      5.00      5.50

Pooled StDev = 0.3283

Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-type

Individual confidence level = 97.80%

B-type = CB(control) subtracted from:

B-type	Lower	Center	Upper
PC	0.0674	0.8900	1.7126
PS	-0.2559	0.5667	1.3893

-0.80      0.00      0.80      1.60

B-type = PC subtracted from:

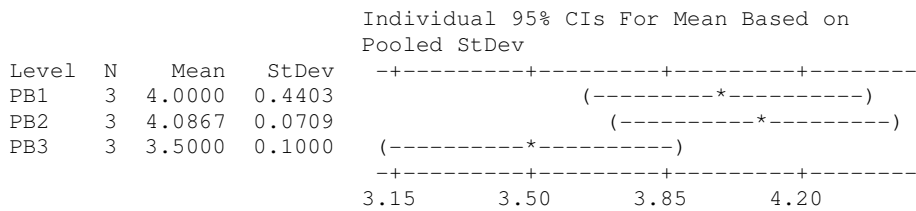
B-type	Lower	Center	Upper
PS	-1.1459	-0.3233	0.4993

-0.80      0.00      0.80      1.60

**One-way ANOVA: Bending strength (28 days) versus Board type (PB1,PB2 & PB3)**

Source	DF	SS	MS	F	P
B-type	2	0.6017	0.3008	4.32	0.069
Error	6	0.4179	0.0696		
Total	8	1.0196			

S = 0.2639    R-Sq = 59.01%    R-Sq(adj) = 45.35%

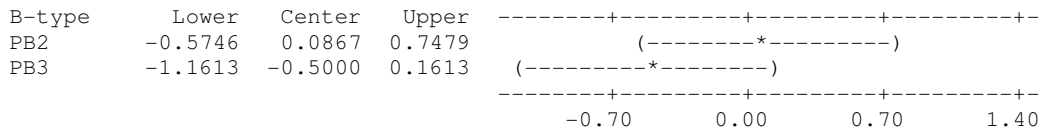


Pooled StDev = 0.2639

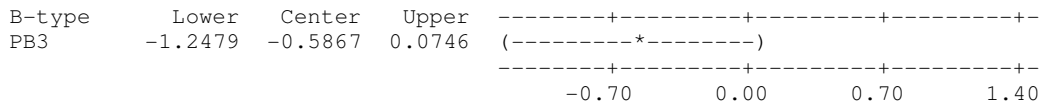
Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of B-type

Individual confidence level = 97.80%

B-type = PB1 subtracted from:



B-type = PB2 subtracted from:



## APPENDIX B

### Conversions

#### 1. Percent Solids and Specific Gravity

To convert between percent solids and specific gravity:

$$S = \frac{K(G-1)}{G} \quad \text{OR} \quad G = \frac{K}{(K-S)}$$

Where:

S = Percent Solids;

G = Specific Gravity;

K = D/(D-1);

D = Density of the Solid Phase.

NOTE: For typical slips and glazes where the density

of the solid phase is 2.6,  $K = 2.6/1.6 = 1.625$

#### 2. A DEGREE BAUME

The Brume scale is a measure of a solution's specific gravity, not its concentration. The French chemist Antoine Baumé devised the scale for marking hydrometers. For liquids that are heavier than water, 0°Be marks the water level of the hydrometer placed in pure water, and 15°Be corresponds to the water level when the scale is placed in a solution that is 15% NaCl by mass. For liquids that are lighter than water, 10°Be marks the level for pure water and 0°Bé corresponds to a solution that is 10% NaCl by mass.

At 60°F, specific gravity can be calculated from degrees Baume using the following formulas:

liquids lighter than water: sp. gr. = $140/(\text{°Be} + 130)$
liquids heavier than water: sp. gr. = $145/(145 - \text{°Be})$

Note that a "new" scale called the Gerlach scale uses 146.78 in the heavier-than-water equation rather than 145.

### Summarization of Baume scale

<p><b>For liquids heavier than water:</b></p> <p>0 °Be = distance the <a href="#">hydrometer</a> sinks in pure water</p> <p>15 °Be = distance the hydrometer sinks in a <a href="#">solution</a> that is 15% sodium chloride (salt, NaCl) <a href="#">by mass</a>.</p> <hr/> <p>To convert from °Be to specific gravity at 60 <a href="#">degrees Fahrenheit</a>: <a href="#">specific gravity</a> = <math>145/(145 - \text{°Be})</math></p>	<p><b>For liquids lighter than water:</b></p> <p>0 °Be = distance the <a href="#">hydrometer</a> sinks in a <a href="#">solution</a> that is 10% sodium chloride (salt, NaCl) <a href="#">by mass</a></p> <p>10 °Be = distance the hydrometer sinks in pure water.</p> <hr/> <p>To convert from °Be to specific gravity at 60 <a href="#">degrees Fahrenheit</a>: <a href="#">specific gravity</a> = <math>140/(130 + \text{°Be})</math></p>
--	--

Although the Baume scale is almost never mentioned in chemistry courses, tradesmen often use it as a convenient way to check solution concentration. For example, U. S. Grade A honey must have a Baume reading of at least 42.49°Be at 60°F. Recipes for lowering the pH of pool water call for 20°Be hydrochloric acid. It's also used by brewers for checking the density of sugar solutions before fermentation

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