AN INVESTIGATION ON MECHANICAL AND THERMAL PROPERTIES OF LIGHTWEIGHT CONCRETE BASED ON THE WOOD-CEMENT SYSTEM

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ABSTRACT

An Investigation on Mechanical and Thermal Propeeties of LightWeight Concrete Based on the Wood-Cement System

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A new genre lightweight concrete based on sawdust-cement materials system has been developed. The concrete was prepared by mixing two sizes of the Maple tree sawdust with the portland cement (type 10) and water for different cement/sawdust ratios which ranged from 1 to 13.

Important mechanical properties (the compressive strength and the bending strength), thermal properties (the bulk density, the water absorption, the boiling water absorption, the drying shrinkage and the thermal conductivity) and the durability (the compressive strength after 300 cycles of a freezing-thawing treatment) of the concrete have been investigated. The effect of the sand addition on the drying shrinkage and the water absorption of the concrete and the effect of the calcium chloride addition on the mechanical strength of the concrete were also investigated.

Results of the study show that the concrete made with the Maple sawdust has low bulk density with moderate strength. It also has low thermal conductivity and high durability. It has higher drying shrinkage and higher water absorption when compared with some other lightweight concretes. Its bulk density, compressive strength and bending strength increase when the cement/sawdust ratio and the bulk density of the sawdust increase. Its compressive strength and bending strength also increase with an increase of the bulk density of the concrete. Its water absorption and drying shrinkage decrease when the cement/sawdust ratio and the bulk density of the sawdust increase. The sand addition improve the drying shrinkage and the water absorption of the concrete. The calcium chloride addition increase the compressive strength and the bending strength of the concrete.

The concrete based on the Maple sawdust and the portland cement can be classified as the low density concrete and the moderate strength concrete. It can be used for residential and commercial building construction for energy conservation.

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LIST OF ABBREVIATIONS AND NOMENCLATURE

A	Average of the Areas of the Upper and Lower Bearing Surface of the Specimen (m^2)
A_h	Cross-Sectional Area of the Main Heater (m^2)
B.S.	Bending Strength (Pa)
B.W.A.	Boiling Water Absorption (%)
C	Cement
C.O.V.	Coefficient of Variation (%)
C.S.	Compressive Strength (Pa)
$C.S._a$	Compressive Strength After Freezing-Thawing Test (Pa)
$C.S._w$	Compressive Strength Without Freezing-Thawing Test (Pa)
D	The Average Depth of Specimen at the Point of Fracture (m)
D_j	Curing Age (day)
D.C.	Durability Coefficient (Between 0 to 1)
D.S.	Linear Drying Shrinkage (%)
F	Maximum Load (N)
G_a	Weight of Oven-Dried Sample in Air
G_b	Weight of Surface-Dry Sample in Air After Immersion and Boiling
G_d	Dry Weight of Specimen
G_t	Wet Weight of Specimen After Soaking t Hours
H	Dry Specimen Height
h_k	Soaking Time (k = 1, 48) (hour)

k	Thermal Conductivity (W/°C)
L	Dry Specimen Length
L_s	Span Length (0.102 m)
ΔL	Change in the Linear Dimension of the Specimen Due to Drying From a Saturated Condition to the Equilibrium State
M	Mass of Dry Specimen (Kg)
Q	Total Input to the Main Heater (W)
r^2	Correlation Coefficient
S	Sawdust
S.D.	Standard Deviation
ΔT	Temperature Difference Across the Sample (°C)
V	Loading Speed of the Testing Machine (1 mm/min.)
W	Dry Specimen Width
W_f	The Average Width of Specimen at the Point of Fracture (m)
X	Mean Value
X_i	An Individual Value
ΔX_b	Bottom Sample Thickness (m)
ΔX_t	Top Sample Thickness (m)
Y	Mean Value
Y_i	An Individual Value
ρ_c	Bulk Density of Concrete (kg/m³)
ρ_{sd}	Sawdust Bulk Density (Kg/m³)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Light-weight concrete fabricated from various material systems is used extensively in the construction industry for building applications. Interest has increased substantially in European, South African and Asian countries on development of concretes which are based on the material system consisting of a mixture of wood-cement since the 1980's [1,2,3].

This is primarily due to the fact that wood-cement products have exhibited useful material characteristics, such as resistances to fire, fungi and insects. These materials also have good durability and high thermal and sound insulating properties. Wood-cement products can be sawn or cut with wood working tools and they can also be fastened with conventional fasteners such as nails, adhesives and screws. As a result of these properties, these products are particularly suitable for building applications.

Wood-cement products are not new, but it is only in recent years that these products have gained popularity. It is not only because of their useful properties as mentioned, but also the developing wood-cement products improve the economic viability of sawmill operations. Successful development of wood-cement products could open a new avenue for the utilization of the Canada wood waste of sawmills in the future.

However, for the concrete formulated with the wood-cement-water process, systematic study and development on the applications, manufacture and properties was still deficient. In spite of numerous publications on the subject of wood-cement composites, information reported in the literature dealt mostly with the development of compatibility of wood-cement and improvement of setting of cement with wood. There is very little technical information about fabrication processes and mechanical and thermal properties of new products. In particular, the properties of lightweight concrete based on Maple tree sawdust mixed with portland cement have not been reported.

The wood-cement-water system is highly wood species-sensitive on the products of wood-cement. Different wood types and their respective different properties will result in variations in the characteristics of the wood-cement end products. It was therefore necessary to carry out in-depth studies on wood-cement systems in order to build up a sufficient basis from which a practical technology could be developed. It was also necessary to study the mechanical and thermal properties of wood-cement composites in order to ensure that technically sound products are eventually manufactured.

1.2 The Objectives of This Project

The objective of this project is to develop a new genre lightweight concrete based on sawdust-cement materials system and to investigate the mechanical and thermal properties of the concrete. The information generated from the study would provide a simple manufacture method and valuable data to the construction industry for the utilization of these products and for the preparation of the products in terms of selection of mixture composition with respect to product characteristics.

In this project, the lightweight concrete made with Maple tree sawdust and portland cement was investigated. The research program of this study is mainly to determine the mechanical properties including compressive strength and bending strength, thermal properties including bulk density, water absorption, boiling water absorption, drying shrinkage, thermal conductivity, and the durability of the lightweight concrete, and to also investigate the effect of the calcium chloride additive on the mechanical strength of the lightweight concrete and the effect of sand addition on the drying shrinkage and the water absorption of the lightweight concrete made by the Maple sawdust and portland cement. The detail research program is described in Chapter-3.

CHAPTER 2

LITERATURE REVIEW

2.1. History of Wood-Cement Products

Sawdust has been used as an aggregate from time to time for making lightweight concrete, which has a history dating back at least to the beginning of this century. It was first investigated at the Building Research Station in the period beginning about 1924 in connection with one particular process of manufacture. A concise report of using sawdust as an aggregate was given by Parker in 1947 [4].

The early commercially successful combination of wood-cement products were the wood wool-cement boards which was known in Europe under the name of "Heraklith" in 1914 [3], and the wood wool-cement boards appeared in North America as "Excelsior" board in the 1940's [1]. This board became very popular in Germany which was still the largest producer of wood wool-cement building panels [3].

During the Second World War wood particles, such as wood shaving and wood chip, were used as aggregates in various types of concrete products, mainly due to the shortage of suitable inorganic materials [3]. In the sixties the cement-bonded particleboard led to the development by Elmendorf, Inc. of a high-density wood-cement board for the building industry [5]. Further developmental work by the Swiss company, Durisol AG followed which led to the production of a smooth, fine-grained, cement-enriched surface, characteristic of the present-day boards and sold under the name of "Duripanel". Now these products have been developed and produced in many other countries, such as Germany, Hungary, Finland, Malaysia, Vietnam, Japan, Italy and Mexico. The "Duripanel" products were first imported into the United Kingdom in Mid-1978 under the names "Fulgurit" and "Granyp" respectively. Table-2.1.1 shows the particleboards available in the market of the United Kingdom up to early 1983 [1].

2.2. Products on Market

At present, the wood wool-cement board is probably the best known product. West Germany and Japan are by far the largest products of wood wool-cement boards and they are responsible for at least 70 per cent of the world production. In these countries the wood wool-cement panels are produced in semi and fully automatic plants [6]. The Tropical Product Institute of the U.K. has been promoting the concept of simple manufacture of wood wool-cement boards in the developing countries for many years [3].

Table-2.1.1. Wood-Cement Particleboards Produced up to Early 1983 [1].

U.K.Trade Name	Manufacturer	Location	Density Capacity of plant (M^3/Day)	Comments
Duripanel	Durisol AG	Dietikon (Switzer-land)	30	Up to 1979
Duripanel	Eternit	Neubeckum Germany	150	From 1981
Fulgurit/ Cemchip	Fulgurit V mbH	Wunstorf (Germany)	50 + 30	A BISON-WERKE Plant, Extended 1979
Granyp	West Hungarian Timber Combine	Szombathe-ly (Hungary)	160	On Three Shifts: A BISON-WERKE Plant
Lives Mineral	Metsaliiton Teollisuus Oy	Hameelinna (Finland)	?	Magnesite Bonded
Tacpanel	Comboard (Malaysia) Sdn Bhd	Kuala Lumpur (Malaysia)	120	A BISON-WERKE Plant
-*	-	Vietnam	20	Original Pilot Plant
-*	-	Japan	120	A BISON-WERKE Plant
Famapand*	Fama	Milan (Italy)	40	-
-*	-	Mexico	120	A BISON-WERKE Plant

* Not imported.

Durisol is a Swiss company, which has been producing light-weight, wood-cement, hollow core, interlocking blocks for many years. These blocks are dry-stacked and the hollows are filled with concrete. This system has allowed their application for construction of ten-storey high buildings [3].

Lignacite is a product available in different shapes and qualities in the United Kingdom. The products are either solid brick or hollow core blocks of various densities (from 1340 to 1600 kg/m^3) which fully meet the requirement of the United Kingdom building standards. The product is particularly popular for farm and factory buildings. It is a fair face material and generally is not plastered [3].

Wood-cement composite blocks are manufactured on a large scale in Germany and Austria. These products are also utilized in the USSR and USA.

The most sophisticated product in this category is the cement-bonded particleboard. These products are becoming increasingly popular for use in prefabricated and factory-built houses. Plants to produce complete buildings were constructed in Mexico, the USSR and the Far East [3].

2.3. Properties of Wood-Cement Products

Some of characteristics and material requirements of cement-bonded wood composites are summarized in Table-2.3.1. [2].

Generally, the bending strength of other wood-cement products is relatively low with the exception of the cement-bonded particleboard, which has a relatively high density. This means that board of thicker dimensions must be used if a load-bearing function is to be performed. The cement-excelsior board was reported possessing bending strength that could meet the industrial standards by Lee [7,8]. Herzig et al. [9] reported on the strength properties of cement-bonded particleboards which were used after 12 years as facade board in Switzerland. The bending strength was 14.1 N/mm^2 which was higher than the required 9 N/mm^2 for such building boards. There were no signs of degradation of the bonds between the wood and cement. Some bigger wood particles which were found on the facade surface showed signs of swelling.

The thermal insulating properties of wood-cement products are quite good and the low combustibility or non-combustibility is of extreme importance. In fact, the combination of these two properties makes these panels a material of outstanding fire endurance.

Table-2.3.1. Some Characteristics and Material Requirements [2].

Characteristic	Medium-Density Composites		Higher-Density Composites
Structure of Material	Coarse-Pored	Porous	Compact
Wood Particle	Wood-Wool	Flakes, Shavings, Slivers, Sawdust	Flakes, Shavings
Dimension Length (cm) Width (mm) Thickness (mm)	 -50 3-6 0.2-0.5	 0.4-7 2-15 up to 6	 1-3 1-3 -0.3 for core, fine
Products	Boards	Boards, Moldings	Boards, Moldings
Density (kg/m^3)	360 - 570	450 - 800	1000 -1350
Bending Strength (MPa)	0.4 - 1.7	0.4 - 2.0	6 - 15
Compressive Strength (MPa)	0.4 - 1.2	0.5 - 2.5	10 - 15
Thermal Conductivity (W/mK)	0.09-0.14	0.1 - 0.2	0.19 - 0.26
Sound Insulation dB*	-31[a]	-31[a]	32 (12 mm thick)
Resistance to Wood Destroying Fungi and Insects Resistance	resistant	resistant	resistant
Fire Test by DIN 4102	B1	B1	B1 A2 (Special boards)

* By DIN 52210 a 5 cm thick boards and 0.4 cm plaster on each side

A2, incombustible; B1, low flammability

Table-2.3.1. Continue

Characteristic	Medium-Density Composites		Higher-Density Composites
Material Requirements Wood (Kg/m^3) Cement (Kg/m^3) Additives Kg/m^3 Water (L/m^3)	 120 - 280 180 - 350 6 - 8 200 - 390	 200 - 400 200 - 400 5 - 10 150 - 400	 250 - 300 750 - 850 20 - 43 300 - 400
Trade Names	Wood-Wool Boards, Exelsior Boards	Arbolit (USSR), Velox (Austria) Durisol (Switzerland)	Century Boards (Japan), Duripanel (Switzerland), Golden Boads(Japan), Betonyp (Hungaria), Isopanel(Germa ny), Cemboards(Mala ysia)

Dinwoodie and Paxton [1] reported that one of the principal attributes of wood-cement particleboard is its excellent performance in fire tests. A class I rating for this product has been achieved in the "Surface spread of flame" test as set out in BS 476: part 7 (1971) and class 0 in the "Ignitability" and " Fire propagation" tests in BS 476: part 5 (1979) and Part 6 (1981) by United Kingdom fire testing laboratories. In Germany it is rated as category B_1 of DIN 4102 part 1, that is, "Hard to burn".

Recent developments by one manufacturer have led to the very recent production of a board satisfying the requirements of the Germany category A_2 of DIN 4102, the second of two incombustibility classes. Test boards produced in the same factory and incorporating further additives have been evaluated in the United Kingdom and have met the requirements of BS 476: part 4, that is, they are "Noncombustible".

Wood-cement products also have quite good sound insulating properties. The relatively thin panels can meet very stringent requirement of the sound insulation. Manufacturers claim that a 33-dB rating can be achieved from an 18-mm board [1]. However, one drawback of the high density of the product is in its handling since an 18-mm thick board 2800x1250 mm weighs about 75 kg. Also, the middle section of thin boards must be supported when being lifted, to avoid fracture.

In the case of coarse-surfaced porous boards [6], these can be easily plastered and they hold plaster well. Surprisingly, in spite of high drying shrinkage (compared to standards set for concrete), the dimensional stability of the plastered external wall has never been a problem and plaster cracks are not common. Panels with a compact surface (particleboard) have an excellent durability against exterior exposure and only finishing with a normal exterior paint is required, mainly for aesthetic reasons.

Wood-cement products were found to have excellent resistance against fungi attack, and even after 30 years in contact with soil, very little deterioration was exhibited due to soft rot and white rot [10]. Wood-cement products also are resistant against powder-post beetles and wood-inhabiting insects [2]. Termites are reported not to be attracted by wood-cement composites. It should pointed out that such composites do not contain repellent or toxic compounds. An impregnation with wood preservatives is generally not required. An important property is that these products can be machined with normal woodworking tools [6].

One of the major drawbacks of the wood-cement composites is that their dimensional movement is considerably greater than other concrete products due to moisture content change. The drying shrinkage is in the range of 0.2 to 0.5 per cent. This will limit the applications of wood-cement products. The addition of sand had a beneficial effect on drying shrinkage, but the disadvantage of sand is that density and thermal conductivity of products are increased [11,12,]. Concrete with high pressure steam curing has been also used to reduce the drying shrinkage. The reduction may vary from 10 to 40 percent [13,14,15].

In summary, it can be stated that wood-cement products posses a unique set of properties, making them practically suitable for building applications [6].

2.4. Uses of Wood-Cement Products

Due to the unique properties of wood-cement products, their major applications would be in buildings construction.

2.4.1. Wood Wool-Cement Products

Wood wool-cement products have the widest utilization in comparison with other wood-cement composites [2, 7]. They are usually used as partitions, ceilings, wall cladding of buildings, roofing, permanent shuttering and acoustic applications, but they are mostly used as insulation boards. Wood wool-cement boards are also used for the construction of low-cost and pre-fabricated houses. However, wood wool-cement products have not yet been accepted for external load bearing wall applications.

2.4.2. Wood-Shavings Products

Wood-shavings products and similar products appear to be used mainly as insulating materials [6]. These products can be produced, using a very simple technology. These panels have been used as a very effective insulating material in the form of thin skins in the cavities of timber frame houses to give them a high thermal, fire and sound performance rating. However, a problem exists for the utilization of the thin wood-shaving panels. This is with respect to achieving a reasonably tight fit into the frames, so that the thin panels can stay in their original skin place position during a fire.

2.4.3. Cement-Bonded Flakeboard Products

Velox and Arbolit boards are two better known products of the cement-bonded flakeboard [2,6]. They are usually used as skins for both single-storey and high-rise buildings. Velox boards are used widely as wall elements and in concrete casing construction. Arbolit boards are used extensively in Russia as wall elements and construction of pre-fabricated houses.

In the case of single or double-storey houses, double skin cavity walls are assembled, using wire clips and no framing is required. The walls are then plastered, but wall papering can be done internally. Another alternative is to use these panels as skins of timber frame houses and the boards are fastened by nails or screws onto the frame. In the case of multi-storey buildings, the double skin serves as permanent shuttering and concrete is poured into the cavity. The end effect is a wall of higher strength and better thermal and fire performance than a wall of the same thickness made from normal concrete.

2.4.4. Cement-Bonded Particleboard Products

Cement-bonded particleboard [6] is one of the few materials which can be successfully used as exterior cladding material without any special precautions apart from normal painting. Although this material is not likely to be cheap in cost per square metre, it can prove to be a very economic material because of its ease of use and since no plastering is required. It can therefore provide extra impetus to the acceptance of timber frame houses.

This material is very suitable for industrialised building systems, where pre-fabricated panels are inserted into load bearing frame or structures. European experience [1] has demonstrated the successful application of wood-cement particleboard for cladding, internal wall lining, and flooring when high resistance to fire or moisture or to both is required for agricultural use. Additional applications have been identified such as fire doors, ventilation ducts, and soffits. In Japan [3] such board are used widely as siding, especially in the Northern part of the country. Bison Worke of Germany [6] developed the "Folding Element" building system. In this system the cement-bonded particleboard panels are V-grooved and folded into units, which are screwed together. Houses can be built, using only this board as structural material. It is also used for the manufacture of roof trusses and roofs. The board is obviously an excellent ceiling panel.

2.5. Effect of Wood on Cement Cure

A major roadblock in the further development of this technology consists of difficulties encountered in the hardening of cement mixed with wood particles. The degree of difficulty varies from species to species, with some species completely blocking cement hydration [16].

Sanderman et al, [17,18] have found that the setting of cement with presence of wood are governed by number of factors, such as geographic, location, felling season, tree species and various tree components. Weatherwax and Tarkow [19,20] have shown that the presence of back, decayed wood, and certain wood carbohydrates can have detrimental effects to the setting of cement. These observation have been found to be supported by other studies [18,21,22,23,24,25,26,27]. In all cases, the species influence on the setting of portland cement have been substantial. Pinion [28], upon examination of a number of European softwood and hardwood species found that the inhibitory influence varied in accordance with the species. Softwood usually presents less difficulties than hardwoods.

"Why does some wood material inhibit cement hydration?" The extractives from wood, namely sugars and tannins have been blamed to prolong the setting time of cement by a number of researchers [17,18,21,24,25,29,30,31]. On the other hand, various pretreatments were suggested and tried with greater or lesser success [20,23,29,31,32,33,34,35,36,37,38,39,40]. Originally the pretreatment was called "mineralisation" of wood. The treatment usually consisted of soaking the wood material in solutions of various chemical additives, which was preceded or followed with washing in hot or cold water. The chemical additives which proved effective were calcium chloride, aluminium sulphate, sodium silicate, lime, gypsum, ferrous sulphate etc. Their common property is that they act as cement cure accelerators. However, different species respond differently to various treatment. Some woods are entirely unsuitable irrespective of chemical additives added, and softwoods were found generally to be less problematic than hardwoods.

In recent years, the wood-cement industries have taken the following steps to improve their products:

1. Prolonging log storage before cutting into particle or wood wool, resulting in a lower sugar content in the wood;
2. Applying preservative to the wood before storage;
3. Coating particles with sodium silicate solution before mixing with cement;
4. Using calcium chloride to expedite the cement hydration.

2.6. Effect of the Wood Particle Shape on Properties of the Products

As it can be logically expected, the wood particle shape has a significant effect on the properties of the wood-cement composites. Surprisingly, this aspect was generally treated quite superficially, and only a few serious investigations in this direction were done. Kayahara [41] has found that the bending strength improved with the increase in the size of the particles, and the wood wool was best in this respect. Prestemon [42] found that sawdust give higher compressive strength than slivers. Dewitz [43] studied, in detail, the geometrical factors involved in making wood-cement moulded products such as hollow core building blocks, and it was concluded that the optimum particles had a length between 2 and 20 mm, a width between 0.2 and 2.5 mm and a thickness of 0.1 to 0.9 mm. The beneficial effect of 10 to 12 per cent wood particle fines on strength was determined by Bubstor [44]. Generally, it was recommended to sieve wood particle fines away, which somewhat contradicts the earlier statement. From this, it appears that the authors did not give the particle shape and size adequate attention.

2.7. Manufacturing Process

For all wood-cement products, the industrial process of manufacture can be summarized as following manner. The debarked logs (or waste wood) are converted into wood wool or suitable particles (wood flakes, strands, shaving etc) and then mixed with a solution of the chemical additive first for controlling the setting process, and the excess solution is removed.

For the wood wool cement products, the wood wool are usually dipped into a tank containing 2 percent sodium silicate solution before mixing with water and additives. The mixture of wood particles, water containing additives and the cement are mixed until the furnish is homogeneous. Water may be added to reach the required consistency. The mixture is placed into oiled mould, these are stacked on top of each other and the stack is compressed by means of weights or a hydraulic press, and clamped. The stack remains clamped until a satisfactory cure is achieved, which depends on ambient conditions or whether external heat is applied. The clamping time varies between 8 and 24 hours. After this curing period, the products are demolded and stacked with stickers in between and left to dry out. Forced drying may be employed. It is essential to use stickers during this stage as the heat of hydration can cause deterioration of strength if the products are left in bulk. After drying, the products are ready for use. The overall production process is illustrated in the following flow diagram [2,7,45,46,47].

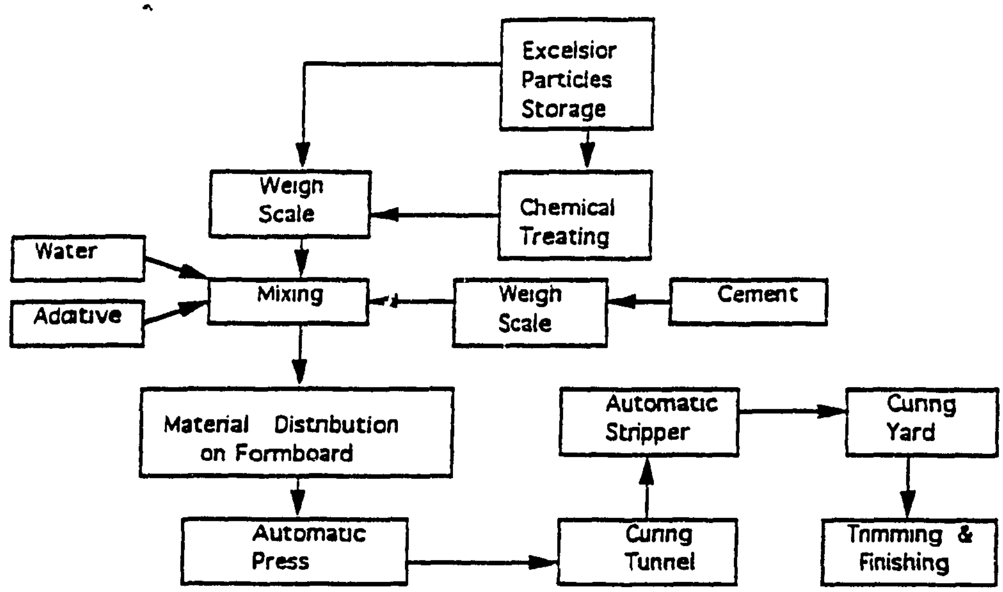


FIGURE-2.7.1. Manufacture Flow Chart of Wood-Cement Products.

CHAPTER 3

EXPERIMENTAL PROCEDURES

3.1 Research Program

The purpose of this research program intends to develop a new genre of lightweight concrete building material based on a sawdust-cement materials system. The main objective of this research program is to characterize the properties of the lightweight concrete in term of the mechanical properties, the thermal properties and the durability. To achieve this objective, the research program of this study is to carry out the following experimental activities.

1. To determine the thermal properties including:
   a) 7 days and 28 days bulk density of the concrete, and bulk density of the concrete changes against cement/sawdust ratio;
   b) water absorption and boiling water absorption of the concrete for curing age of 28 days, and water absorption and boiling water absorption of the concrete change against cement/sawdust ratio;
   c) drying shrinkage of the concrete for curing age of 28 days, and drying shrinkage changes

against cement/sawdust ratio;

d) thermal conductivity of the concrete for curing age of 28 days, and thermal conductivity changes against bulk density of the concrete.

2. To determine the mechanical properties including:

   a) 7 days and 28 days compressive strength of the concrete, and the compressive strength change against cement/sawdust ratio;

   b) 7 days and 28 days bending strength of the concrete, and the bending strength changes against cement/sawdust ratio.

3. To determine the Durability of the concrete.

4. To investigate preliminarily the effect of chemical additive ($CaCl_2$) on the mechanical properties of the concrete.

5. To investigate preliminarily the effect of addition of sand on the drying shrinkage and the water absorption of the concrete.

3.2 Materials

This research program investigates the concrete which was made by mixing sawdust with portland cement and water. Two different sizes of the Maple tree sawdust were used for the investigation. The sawdust was obtained from a local sawmill in the province of Quebec. The properties of the sawdust and cement utilized are documented in Table-3.2.1.

Table-3.2.1 The properties of the sawdust and cement utilized.

Sawdust	Bulk Density(Kg/m^3)	Moisture Contents %
No.1	194	6
No.2	218	6
The Portland Cement is TYPE 10 (ASTM TYPE I)		

3.3. Specimens Preparation

The experimental procedures for specimen preparation described on this section are applicable to two sizes of Maple tree sawdust mixed with portland cement. The cube mold which was used to prepare the specimens for measurement of compressive strength, water absorption and boiling water absorption, and durability of the concrete is show in Figure-3.3.1. The dimensions of the mold are 50 by 50 by 50 mm^3. The

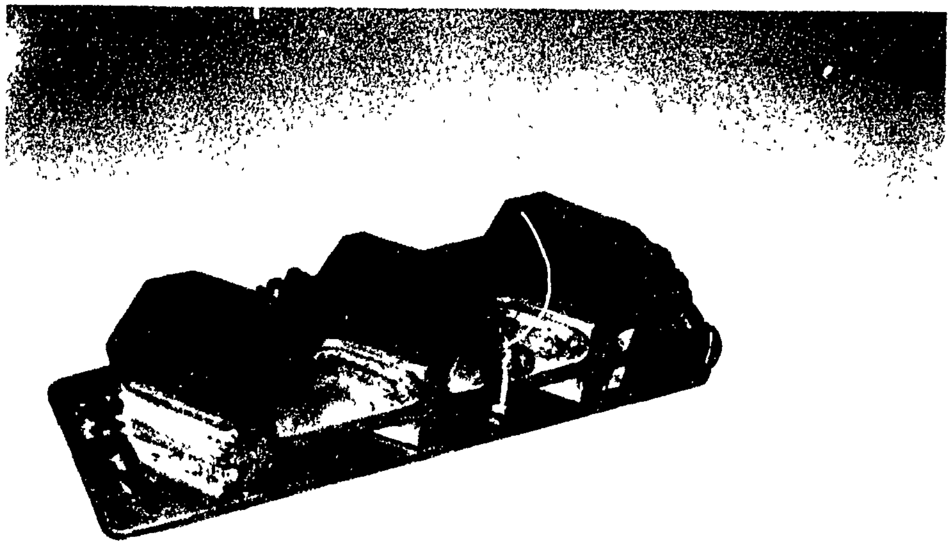


Figure-3.3.1. The Mold for Compressive Strength Specimen.

specimens for the compressive strength test were also used to measure the bulk density of the concrete. The rectangular mold which was used to prepare the specimens for measurement of bending strength and drying shrinkage of the concrete is show in Figure-3.3.2. The dimensions of this mold are 50 by 50 by 150 mm^3. The round mold which was used to prepare the specimens for measurement of thermal conductivity of the concrete is shown in Figure-3.3.3. The diameter of this mold is 203 mm and the thickness is 26 mm. The detail procedure for preparation of specimens involved the following steps.

1. Weigh the sawdust and portland cement according to the design cement/sawdust ratio and the amount of required water. The details are shown in Table-3.3.1. and Table-3.3.2. The amount of water used for mixing was selected to be 2.7 millilitre per gram of sawdust and 0.25 millilitre per gram of cement for size of No.1 sawdust based on test results reported by Weatheawax and Tarkow [19]. Because the size of No.2 sawdust is different from the size of No.1 sawdust, the No.2 sawdust would not have the same degree of water absorption. For sizes of No.2 sawdust, the amount of water used for mixing was adjusted properly to be 1.7 millilitre per gram of sawdust and 0.25 millilitre per gram of cement.
2. Put the portland cement into a mechanical blender

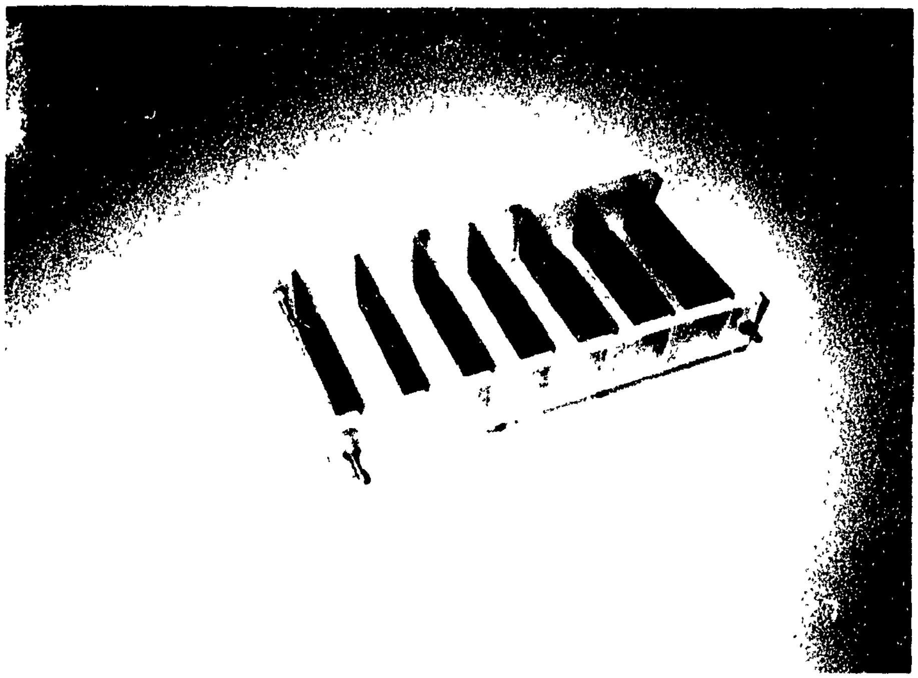


Figure-3.3.2. The Mold for Bending Strength Specimen.

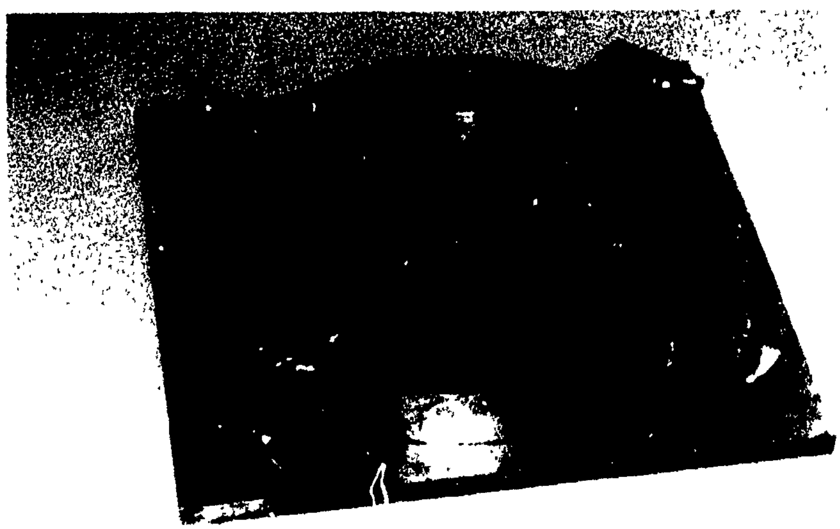


Figure-3.3.3. The Mold for Thermal Conductivity Specimen.

Table-3.3.1. Cement/Sawdust Ratio and Range of Compositions for Size of No.1 Sawdust.

Cement/Sawdust	Sawdust (g)	Cement (g)	Water (g)
1.0	200	200	590
2.0	200	400	640
3.0	200	600	690
4.0	200	800	740
5.0	200	1000	790
6.0	200	1200	840
7.0	200	1400	890
8.0	200	1600	940
9.0	200	1800	990
10.0	200	2000	1040
11.0	200	2200	1090
12.0	200	2400	1140
13.0	200	2600	1190

Table-3.3.2. Cement/Sawdust Ratio and Range of Compositions for Size of No.2 Sawdust.

Cement/Sawdust	Sawdust (g)	Cement (g)	Water (g)
2.0	200	400	390
3.0	200	600	440
4.0	200	800	490
5.0	200	1000	540
6.0	200	1200	590
7.0	200	1400	640
8.0	200	1600	690
9.0	200	1800	740
10.0	200	2000	790
11.0	200	2200	840
12.0	200	2400	890
13.0	200	2600	94

and then pour the water slowly into the blender.

3. Mix the water and the portland cement into a paste for 3 minutes. Then add the sawdust into a blender.
4. Mix the cement paste and the sawdust thoroughly into a good mixture.
5. Then pour the mixture into the oil molds and smooth the surface flat and even.
6. Let the specimens dry in air for 24 hours.
7. Remove the specimens out of the mold and put into water at 23 °C for 7 days or 28 days.
8. After curing in water, dry the water saturated specimens in an oven at 105 °C for 48 hours.
9. After the drying process, cool the specimens to room temperature. Then these specimens are ready for testing.

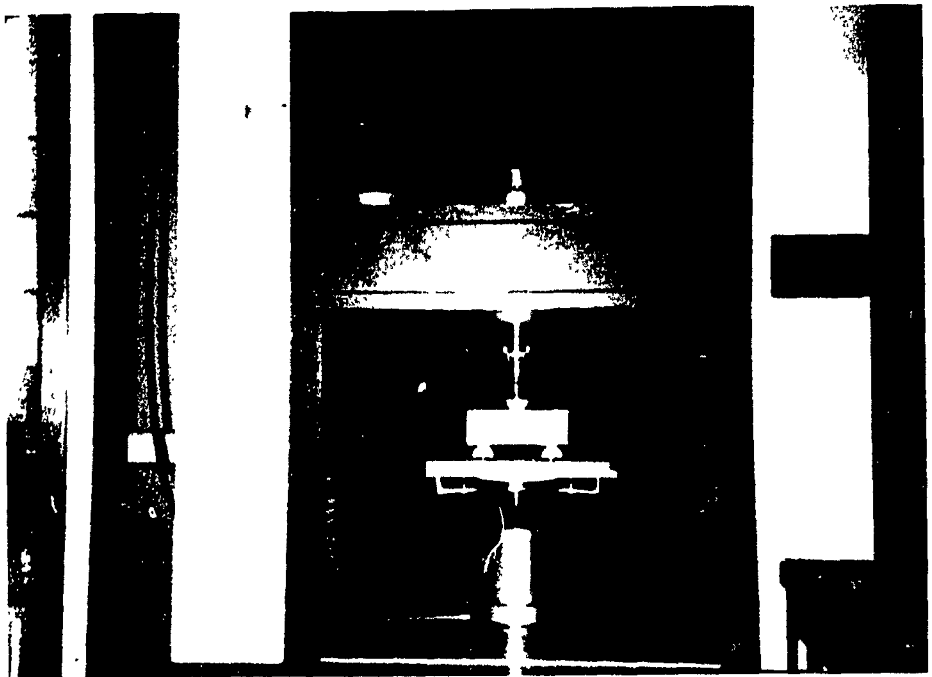
3.4. Properties of the Concrete Measurement

3.4.1. Compressive Strength Measurement

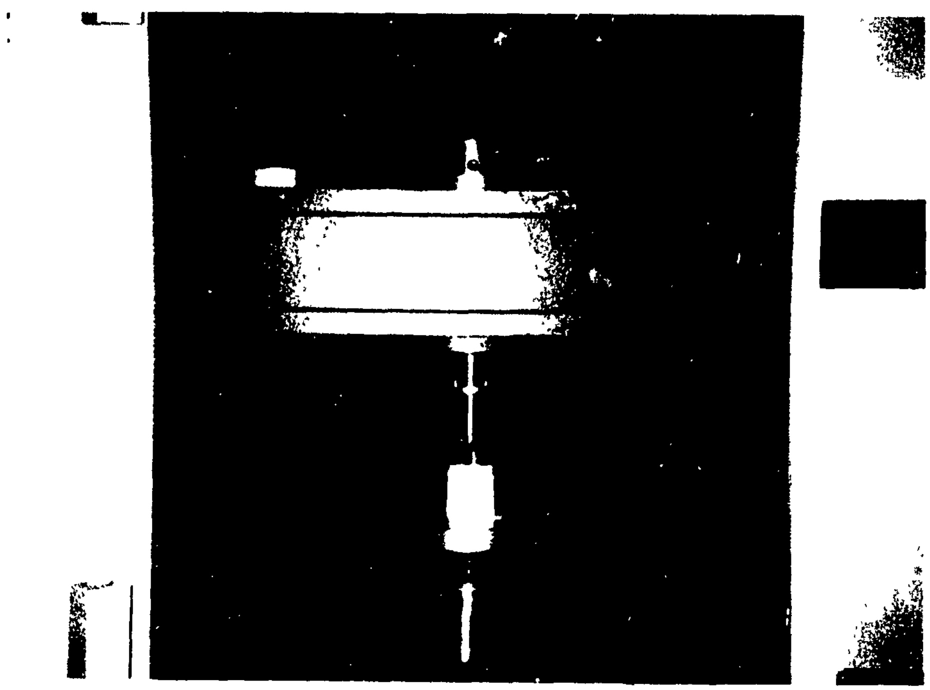
The compressive strength was determined in accordance with ASTM test method No. C495-80 [48]. The specimen preparation for the compressive strength test was described in Section 3.3. The compressive strength of the specimen was measured using an INSTRON Testing machine which is shown in the Figure-3.4.1.1. Six specimens for each ratio of cement to sawdust for two sizes of sawdust were tested and the average result was calculated. The test load was applied perpendicular to the specimen surface at a loading rate of 1 mm/min until failure occurred. The yield point was used to determine the compressive strength. The calculation equation of the compressive strength is shown in Appendix 1.

3.4.2 Bending Strength Measurement

The bending strength was determined in accordance with ASTM test method No. C293-79 [49]. The specimen preparation for the bending strength test was described in Section 3.3. The bending strength was determined using a 3-point system with a loading at the midspan with the INSTRON testing machine. The load was applied at the upper surface of the specimen is shown in Figure-3.4.1.1. The loading rate of the testing machine for



Bending Strength Testing



Compressive Strength Testing

Figure-3.4.1.1 Instron Testing Machine.

bending strength test was 1 mm/min. Six specimens for each ratio of cement to sawdust for two sizes of sawdust were tested and the average result was calculated. The calculation equation of bending strength is shown in Appendix 2.

3.4.3 Bulk Density Measurement

The bulk density was determined accordance with ASTM test method No. C495-80 [48] by dividing the dry mass of the specimen by the volume of the specimen. The specimens prepared for the compressive strength test were used for measurement of the bulk density of the concrete. The dry mass of the test specimen was measured to an accuracy of about 0.1 %. and the sizes were measured to an accuracy of about 0.2 mm. Six specimens for each ratio of cement to sawdust for two sizes of sawdust were measured, and the average result was calculated. The calculation of the bulk density of the concrete equation is shown in Appendix 3.

3.4.4 Water Absorption Measurement

The water absorption was determined in accordance with ASTM test method No. C642-80 [50]. The specimens for water absorption test have a curing age of 28 days. The specimens prepared for water absorption test is described in Section 3.3. The weight of the dry specimen was weighed to an accuracy of 0.1%. Then the dry specimens were immersed in water at room temperature for 1 hour, 24 hours and 48 hours. After soaking in water, the water on the surface of the specimen was wiped with soft cloth, and the specimen was weighed to an accuracy of 0.1 %. The measuring of each specimen was carried out within 2 minutes after removing the specimen from water. The ratio of the difference between the wet weight and the dry weight to the dry weight is considered to be the water absorption. Six specimens for each ratio of cement to sawdust for two sizes of sawdust were tested and the average result was calculated. The calculation of the water absorption equation is shown in Appendix 4.

3.4.5 Boiling Water Absorption Measurement

The boiling water absorption was determined in accordance with ASTM test method No. C642-80 [49]. The specimens that have been subjected to the water absorption measurement were re-immersed in a water bath. The water around the specimen was allowed to circulate freely on all side of the specimens. The water was then heated to boiling within a period of about 1 hour. The specimens were allowed to remain in the boiling water continuously for a period of 5 hours. It was then allowed to cool to room temperature by natural cooling about 8 hours. After cooling process, the saturated specimens were removed from the water and the water on the surface of the specimens were wiped with soft cloth and then each of the specimens were weighed to an accuracy of about 0.1 %. Six specimens for each ratio of cement to sawdust for two sizes of sawdust were tested and the average result was calculated. The calculation of the boiling water absorption equation is shown in Appendix 5.

3.4.6. Drying Shrinkage Measurement

The drying shrinkage was determined in accordance with ASTM test method No. C426-80 [51] with the equipment of measurement is shown in the Figure-3.4.6.1. The following procedure was carried out:

1. The sizes of specimens were 50 by 50 by 150 mm^3, and the specimens had curing age of 28 days.
2. The specimen preparation for the drying shrinkage test was described in Section 3.3.
3. The length of dry specimens was measured at the centre of the opposite ends of the test specimens. In order to obtain reading of length of the specimen as accurate as possible, the test specimens were installed with the gage plug with a spherical shaped head on centre of opposite ends of the specimens. Then the specimens were immersed in water at 23 °C for 48 hours.

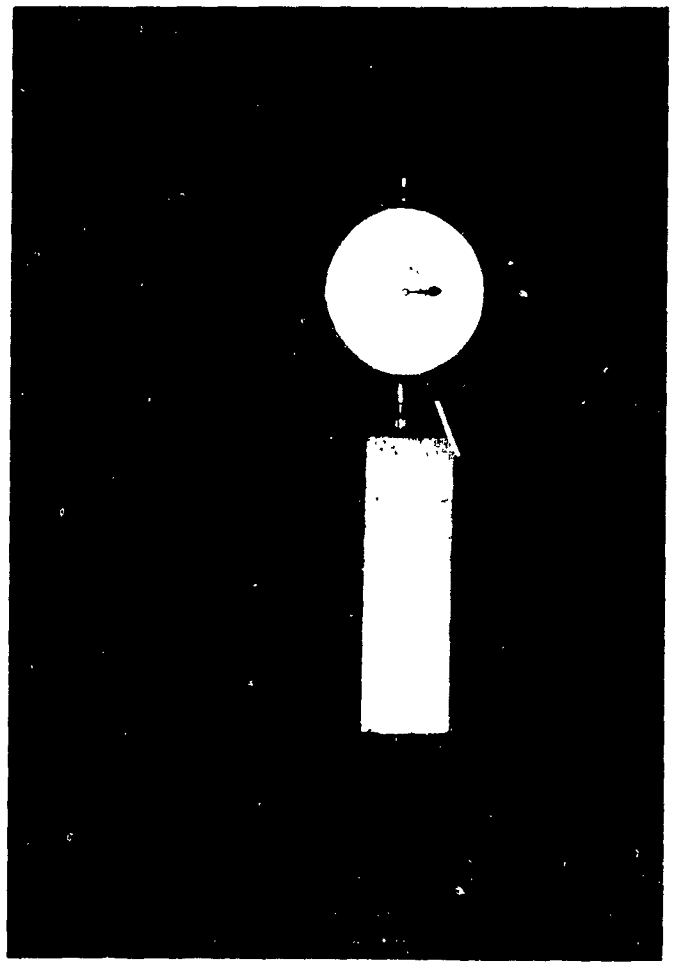


Figure-3.4.6.1 Measurement Equipment for Drying Shrinkage.

4. After removing the specimens from water, the initial-length reading on the test specimens was obtained to an accuracy of 0.025 mm.
5. After drying the specimens in room air for 2 days, the test specimens were stored for drying in an environmental chamber at 50 °C and a relative humidity of 17 percent for 3 days.
6. At the end of 5 days of drying, the shrinkage test specimens were removed from the drying oven and cooled the specimens in a sealed chamber with a thermometer to 23 °c about one day. Following cooling, the specimen length reading was obtained.
7. The test specimens were returned to the drying oven for a second period of drying. The duration of the second, and subsequent, drying periods was 48 hours. Following the second period of drying and repeated cooling, the length reading was measured.
8. The 48 h periods of drying in the oven was continued followed by length determination after cooling under the specified conditions until an equilibrium condition of the shrinkage specimens had been reached; equilibrium is considered to be the prevailing condition when the average length change of the specimens is 0.002 percent over a span of 6 days of drying.
9. Six specimens for 6 ratio of cement to sawdust for

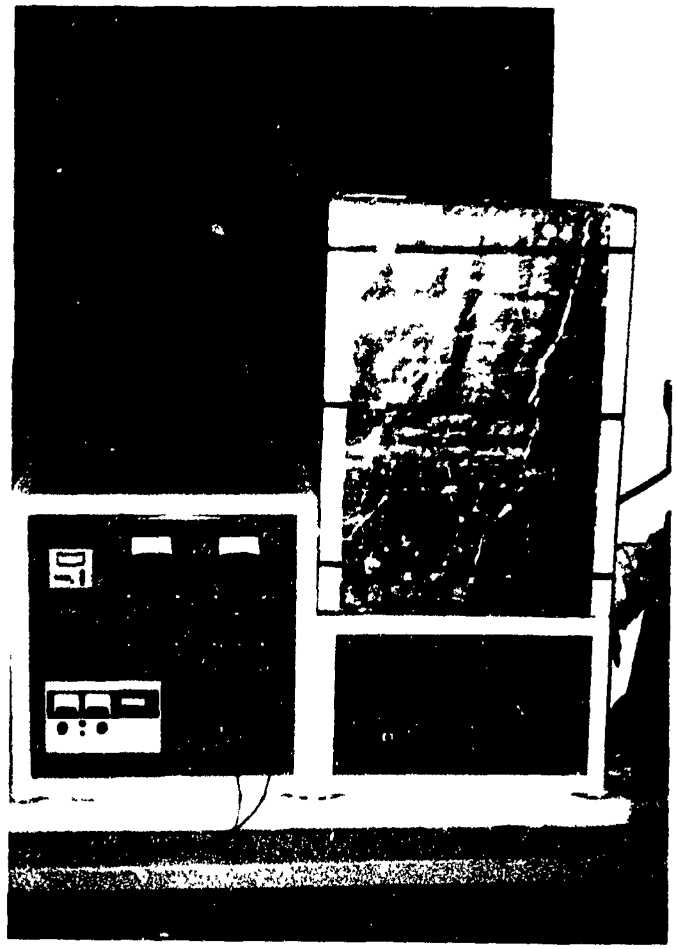


Figure-3.4.7.1 Dyratech Guarded Hot Plate Apparatus.

two sizes of sawdust were tested and the average result was calculated. The calculation of the drying shrinkage equation is shown in Appendix 6.

3.4.7 Thermal Conductivity Measurement

The thermal conductivity of the specimens was determined employing a Dynatech Guarded Hot-Plate Apparatus, which is shown in Figure-3.4.7.1, according to the procedure described in the ASTM test method NO.C177-79 [52]. One pair of specimens both with the same weight and measuring 203 mm in diameter and 26 mm in thickness was prepared for the thermal conductivity test. The specimen preparation was described in Section 3.3. The specimens which were made with No.1 sawdust and cement had a curing age of 28 days. The following procedure was carried out:

1. The thickness of each test specimen was measured to an accuracy of about 0.01 mm;
2. The specimens were mounted on the test column of the guarded hot-plate apparatus such that the heater was in close contact with the surfaces of test specimens;
3. A known electrical power was input to the heater of the apparatus, so that it would generate a constant mean temperature of about 25 °C in the specimen when

the steady state condition was attained;

4. The temperature differential across the specimens between the hot surface and the cold surface was maintained at about 14 °C;

5. The temperature distributions on the hot surface and on the cold surface, the temperature differential across the specimen, and the electrical power input to the apparatus were measured in 1 hour intervals;

6. The thermal conductivity value and the thermal resistance corresponding to the thickness of the specimen, and the mean temperature of the test specimen were also calculated. These calculations were also carried out in 1 hour intervals;

7. When the steady state conditions in the test were attained and thermal conductivity value deviated equal to or less than 0.3%. the test was completed.

8. Steps 1 to 7 were carried out for measurement at each mean temperature level (15 °C, 24 °C, 35 °C and 45 °C);

9. When the mean temperature in the test specimen was changed, step 1 to 7 were repeated after the temperature of the coolant which was used to cool the cold plate was changed to a pre-determined setting.

10. The calculation of the thermal conductivity

equation is shown in Appendix 7.

3.4.8. Durability Measurement (Freezing-Thawing Cycling Test)

The durability of the specimens was determined by subjecting the specimens to a freezing-thawing cycling treatment using the SOILEST FREEZE-THAW TESTER (Model CT-110) which is shown in Figure-3.4.8.1.

The procedure for the durability test was carried out in accordance with ASTM test method No. C67-80 [53] in the following manner: 12 specimens for each ratio of cement to sawdust were prepared. Six of these specimens of them were employed for freezing-thawing cycling testing. The dimensions of specimens was 50 by 50 by 50 mm^3, and the specimens had a curing age of 28 days. The specimen preparation for the durability measurement was described in Section 3.3. Each of the saturated specimens was then placed in a plastic bag and closed tight. The specimens with the plastic bag together were then placed in the container of the freezing-thawing machine. The instrument was programmed to cool during 2 hour periods down to -17.8 °C, and then to heat during 1 hour periods up to 4.4 °C. The cooling-heating cyclings were continued until a total of 300 cycles were completed. The specimens were taken out of the plastic bag. The specimens were then dried in an oven at 105 °C for 48 hours. After drying, the specimens were

Figure-3.4.8.1 Soilest Freeze-Thaw Tester (Model CT-110).

cooled to room temperature for two hours and then the compressive strength were determined in similar procedures as described in Section 3.4.1.

Six specimens for each ratio of cement to sawdust for two sizes of sawdust were tested for compressive strength after freezing-thawing cycling test and another six same age specimens for each ratio of cement to sawdust were tested for compressive strength without freezing-thawing cycling test. The average result was calculated. The ratio of compressive strength after freezing-thawing cycling treatment to that without treatment was used to determined the durability coefficient of the concrete. The calculation of the durability coefficient equation is shown in Appendix 8.

CHAPTER 4

EXPERIMENTAL RESULTS

The specimens were prepared with two different sizes of sawdust and portland cement for cement/sawdust ratios from 1 to 13. These specimens were found to exhibit different mechanical and thermal properties. Mechanical properties examined included compressive strength and bending strength. Thermal properties examined included bulk density, water absorption, boiling water absorption, drying shrinkage, and thermal conductivity. Variation of these mechanical and thermal properties can be correlated with the bulk density and cement/sawdust ratios. The various results are given under separate headings in following sections. Six specimens for each cement/sawdust ratio were used to calculate all mechanical and thermal properties. The numerical data for each test, the average values and standard deviation and coefficient of variation were given in Appendix 10. The average values were also plotted in graphical forms.

However, in order to obtain a comprehensive understanding of the properties of the lightweight concrete and their dependence on compositions and other variables, such as sawdust bulk density and curing age etc, the results of the mechanical properties and some thermal properties were analyzed by dimensional analysis and regressional analysis. It was hoped that the results could then be applied generally to different set of circumstances and only limited additional experimentations could be needed to obtain relevant quantitative relationships.

4.1 Bulk Density of the Concrete

The average results of concrete bulk density after curing in water for 7 days and 28 days was observed to increase from 436.02 to 1308.12 Kg/m^3 and 454.3 to 1332 Kg/m^3 respectively when the cement/sawdust ratios increased from 1 to 13 for the concrete made with No.1 sawdust and cement, and from 589 to 1476 Kg/m^3 and 595 to 1480 Kg/m^3 respectively when the cement/sawdust ratios increased from 2 to 13 for the concrete made with No.2 sawdust and cement. The bulk density of the concrete as a function of cement/sawdust ratio was shown in Figure-4.1.1. It was observed that the bulk density of the concrete increased as the cement/sawdust ratio increased. For the same cement/sawdust ratio, the results shown the bulk density of the concrete increased slightly as the curing age increased from 7 days to 28 days. It was also observed that the concrete made with higher sawdust bulk density had higher bulk density of the concrete than the concrete made with lower sawdust bulk density based on same

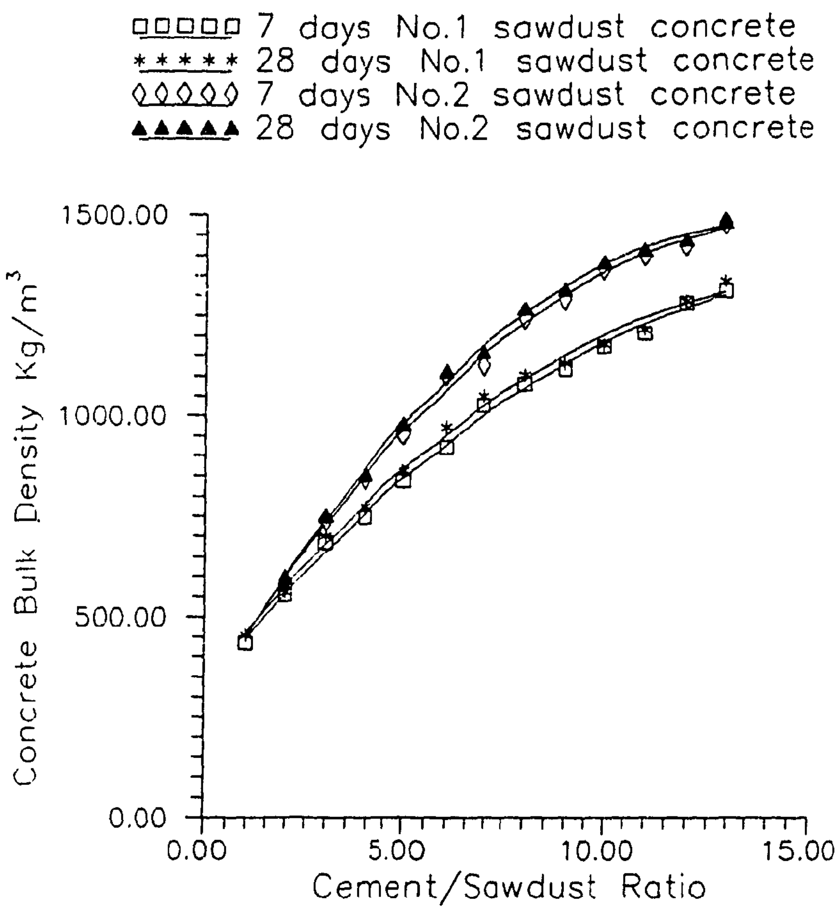


Figure-4.1.1. Bulk Density of the Concrete Versus Cement/Sawdust Ratio.

cement/sawdust ratio.

The relationship between the 28 days bulk density of the concrete and cement/sawdust ratio and sawdust bulk density was determined by dimensional analysis and regressional analysis. The dimensionless equation is shown in Equation 4.1 which is also illustrated in Figure-4.1.2. The result from Equation-4.1 is same as explained in Figure-4.1.1. It indicated the bulk density of the concrete is related to the cement/sawdust ratio but is related to bulk density of sawdust. The experimental results of the bulk density for concrete made by two different sizes of sawdust and the bulk density of sawdust were substituted in the left hand side of equation-4.1 and then it was plotted into Figure-4.1.2. It was seen that the ρ_c/ρ_{si} ratio was highly correlated with C/S ratio (correlation coefficient $r^2 = 0.97$). The calculation of the correlation coefficient is shown in Appendix 9.

Dimensionless Equation-4.1 was shown as following:

$$\rho_c/\rho_{si} = 1.8 + 0.633(C/S) - 0.019(C/S)^2 \qquad (4.1)$$

Where:

ρ_c = 28 days concrete bulk density Kg/m^3

ρ_{si} = Sawdust bulk density Kg/m^3

(i = 1, 2; ρ_{s1} = 194, ρ_{s2} = 218)

C/S = Cement/sawdust ratio

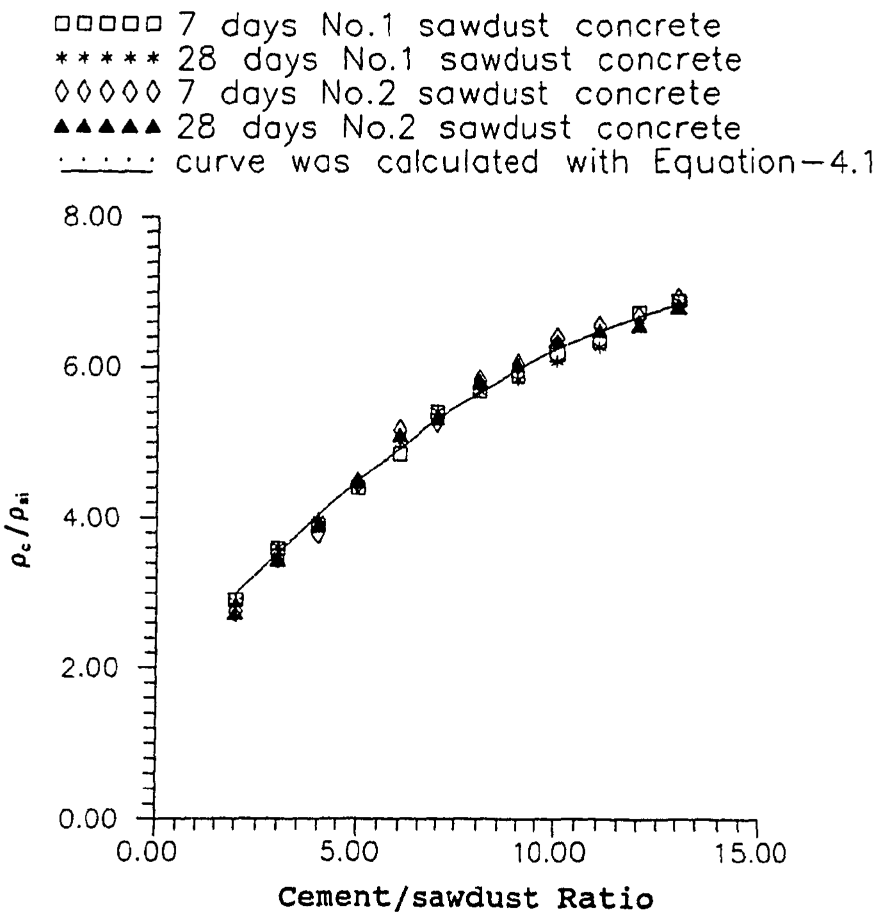


Figure-4.1.2. ρ_c/ρ_{si} **Versus Cement/Sawdust Ratio.**

4.2 Water Absorption of the Concrete

The results of water absorption of the concrete soaking in water for 1, 24 and 48 hours were obtained. It was observed that water absorption of the concrete decreased gradually as the cement/sawdust ratio increased as show in Figure-4.2.1. It indicated that the higher the sawdust contents in the concrete is, the higher the water absorption will be. It was also observed that the water absorption of the concrete soaking in water for 1 hour was about 70% water absorption of the concrete soaking in water for 48 hours and the water absorption of the concrete soaking in water for 24 hours was almost same as the water absorption soaking in water for 48 hours. It meant that the concrete had achieved saturation after soaking in water for 24 hours. For the saturated specimens after soaking in water for 48 hours, the water absorption values decreased from 136.45% to 24.4% as the cement/sawdust ratio increased from 1 to 13 for the concrete made with No.1 sawdust and decreased from 73.73% to 17.44% as the cement/sawdust ratio increased from 2 to 13 for the concrete made No.2 sawdust. It was also seen that the concrete made with lower sawdust bulk density had higher water absorption compared with the concrete made with higher sawdust bulk density based on same cement/sawdust ratio. This is due to the lower sawdust bulk density with greater porosity.

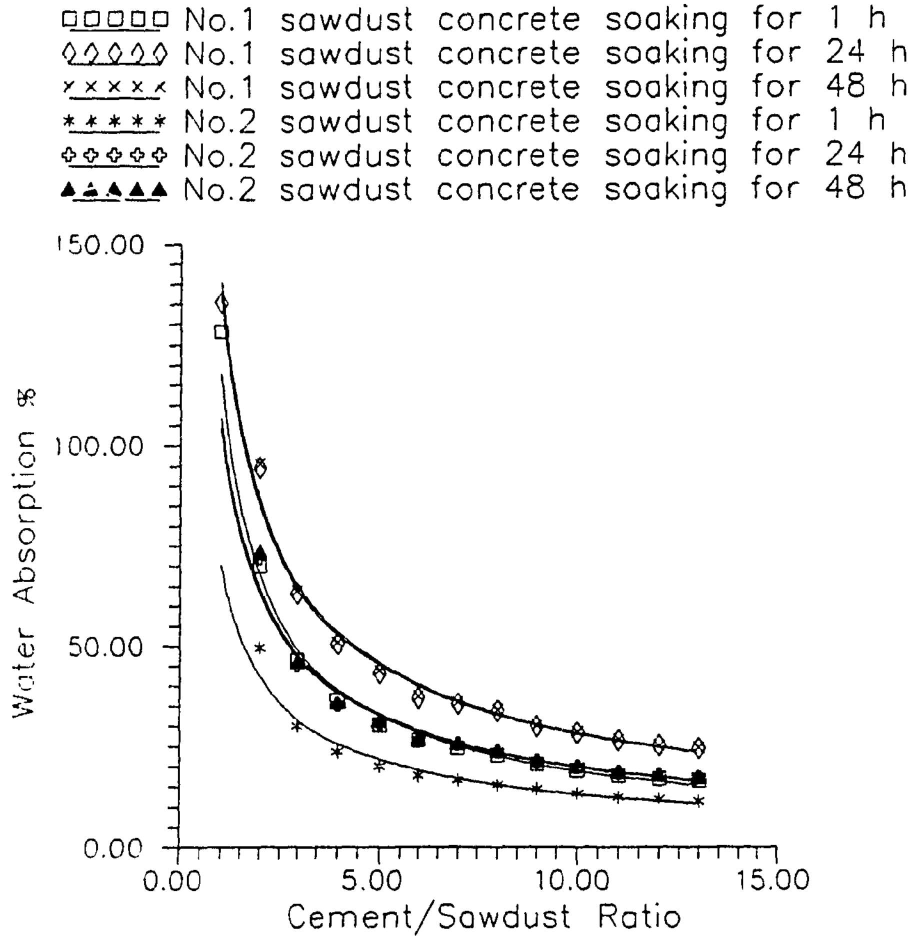


Figure-4.2.1. Water Absorption Versus Cement/Sawdust Ratio.

The relationship between water absorption and cement/sawdust ratio, soaking time for 1 hour and 48 hours and sawdust bulk density was determined by dimensional analysis and regressional analysis. Because the water absorption of the concrete soaking in water for 24 hours was almost same as the water absorption soaking in water for 48 hours, the water absorption soaking in water for 24 hours was omitted during the dimensional analysis. The dimensionless equation is given in Equation 4.2 which is also illustrated in Figure-4.2.2. It indicated the water absorption of the concrete is related to sawdust content in concrete and also related to the structure of sawdust for the same soaking time. The experimental result of the water absorption for the concrete made with two different sizes of sawdust, soaking time for 1 hour and 48 hours and bulk density of the sawdust were substituted in the left hand side of Equation-4.2 and then it was plotted into Figure-4.2.2. It was indicated that the ratio of the $WA/([\rho_{si}/\rho_{s1}]^{-2.8}*[h_k/h_{48}]^{-0.102})$ is highly correlated with the ratio of C/S (correlation coefficient $r^2 = 0.96$).

The Dimensionless Equation-4.2 was shown as following:

$$WA/([\rho_{si}/\rho_{s1}]^{-2.8}*[h_k/h_{48}]^{0.102}) = 104.38(C/S)^{0.724} \qquad (4.2)$$

Where:

WA = Water absorption %

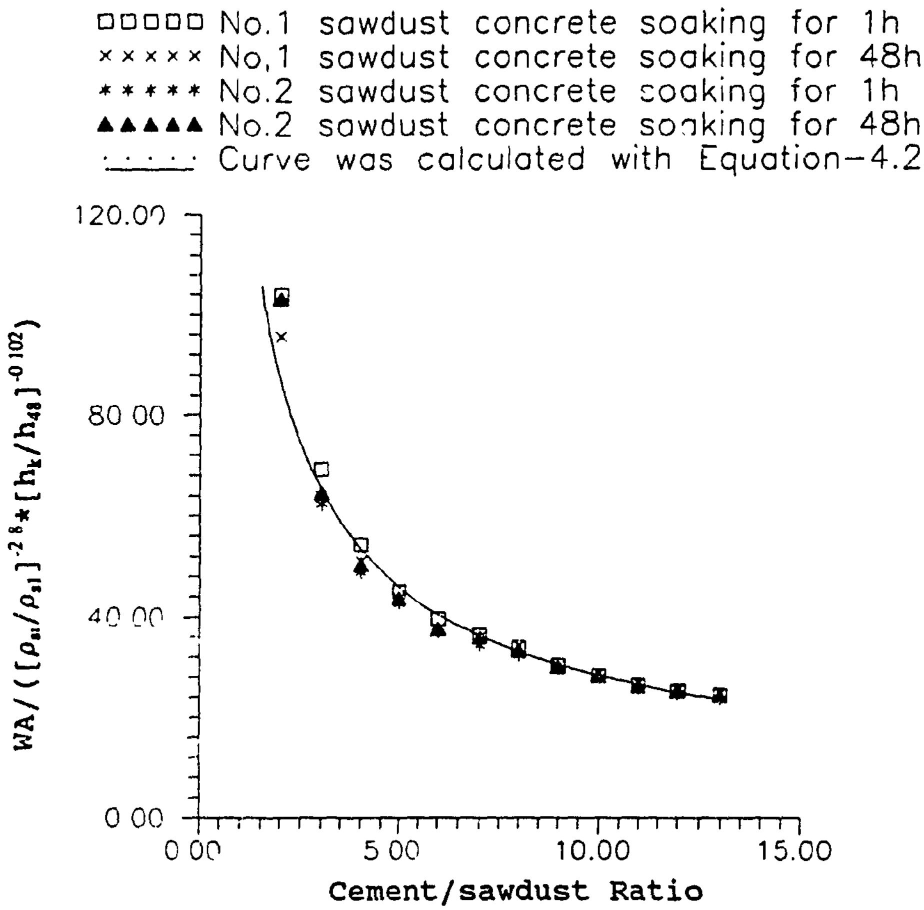


Figure 4.2.2 $WA/([\rho_{si}/\rho_{s1}]^{-2.8} * [h_k/h_{48}]^{-0.102})$ **Versus the Cement/Sawdust Ratio.**

h_k = Soaking time (k = 1, 48) hours

C/S = Cement/sawdust ratio

ρ_{si} = Sawdust bulk density Kg/m^3

(i = 1, 2; ρ_{s1} = 194, ρ_{s2} = 218)

4.3 Boiling Water Absorption of the Concrete

The results of boiling water absorption of the concrete after soaking in boiling water were measured. It can be seen that the boiling water absorption decreased with increased cement/sawdust ratios and increased sawdust bulk density which was shown in Figure-4.3.1. It had ranged from 120.49% to 27.32% for the concrete made with No.1 sawdust when the cement/sawdust ratio was from 1 to 13 and from 90.01% to 21.92% for the concrete made with No.2 sawdust when the cement/sawdust ratios was from 2 to 13. A comparison of the water absorption soaking in water for 48 hours with boiling water absorption was also shown in the Figure-4.3.1. It was also seen that the boiling water absorption of the concrete was higher than the water absorption soaking in water for 48 hours. The boiling water absorption is also related to the sawdust content in concrete and the sawdust structure.

The boiling water absorption with cement/sawdust ratio and sawdust bulk density was also analyzed by dimensional

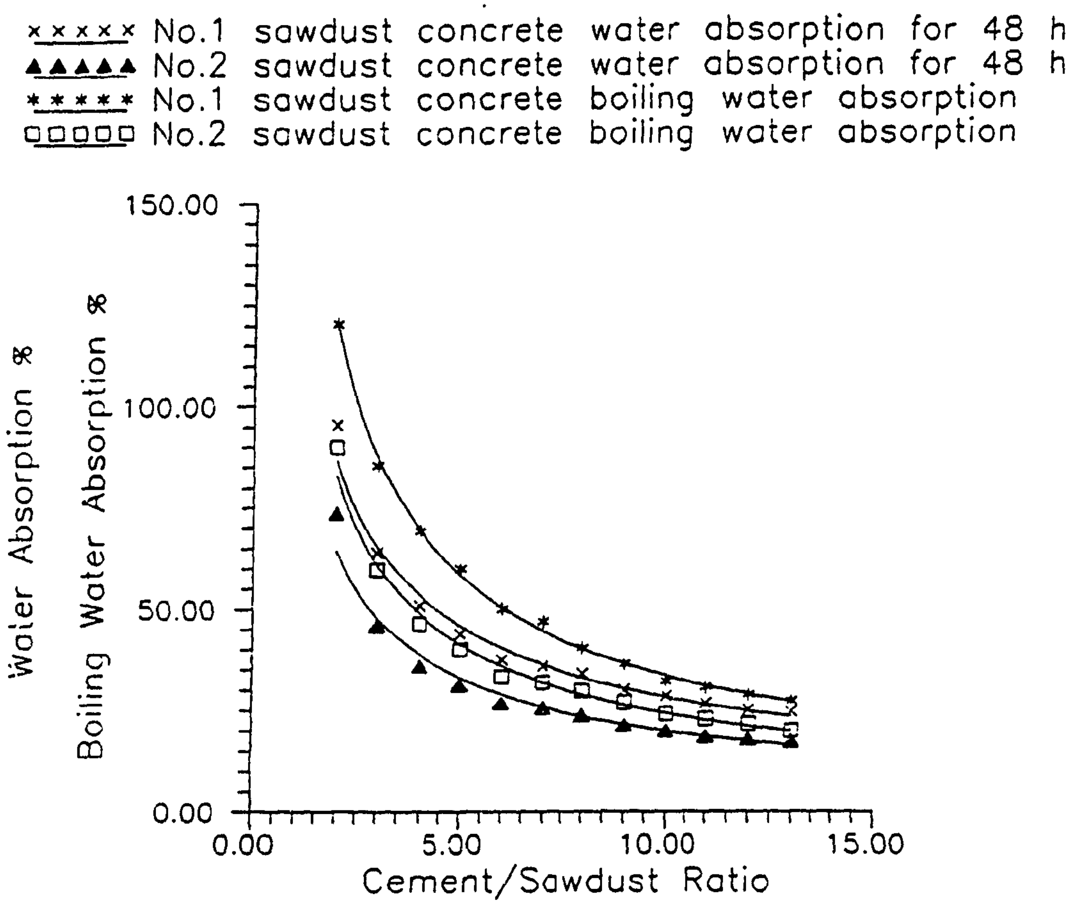


Figure-4.3.1. Comparing the boiling Water Absorption with water absorption soaking in water for 48 hours.

analysis and regressional analysis. The relationship is show in dimensionless Equation-4.3 which is also illustrated in Figure-4.3.2. The experimental result of the boiling water absorption for the concrete made with two different sizes of sawdust and bulk density of sawdust were substituted in the left hand side of Equation-4.3 and then it was plotted into Figure-4.3.2. It showed that the ratio of $BWA/(\rho_{si}/\rho_{s1})^{-2.7}$ is highly correlated with the ratio of C/S (correlation coefficient $r^2 = 0.96$).

The Dimensionless Equation-4.3 is shown as following:

$$BWA/(\rho_{si}/\rho_{s1})^{-2.7} = 216.82(C/S)^{0.8045} \qquad (4.3)$$

Where:

BWA = Boiling water absorption %

ρ_{si} = Sawdust bulk density Kg/m^3

($i = 1, 2; \rho_{s1} = 194, \rho_{s2} = 218$)

C/S = Cement/sawdust ratio

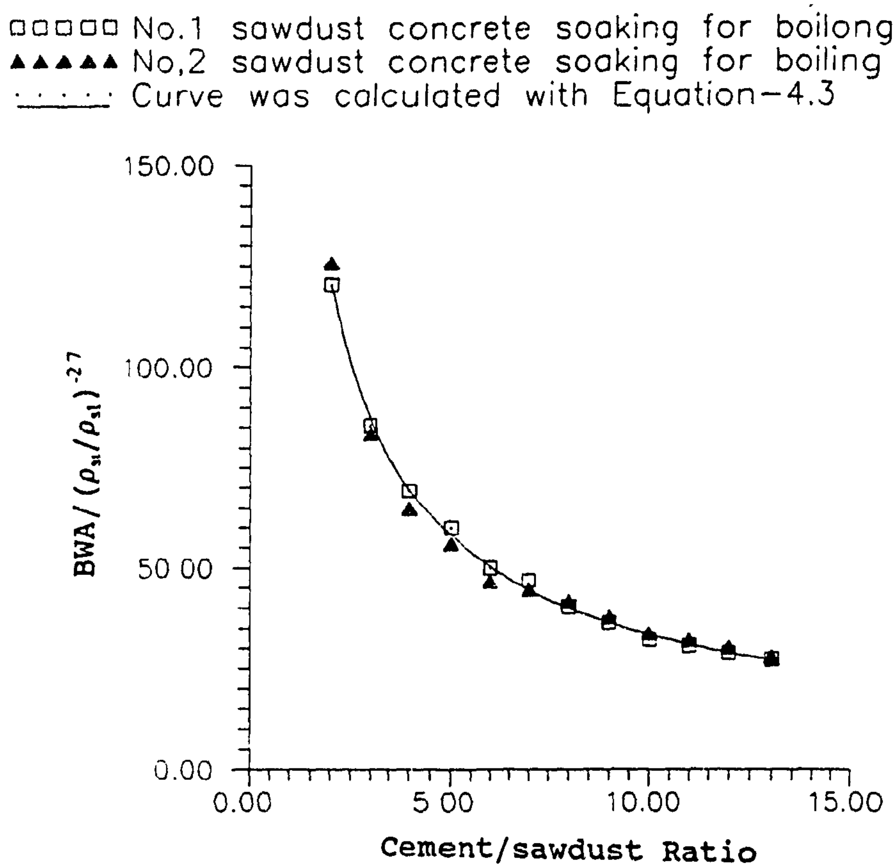


Figure-4.3.2. BWA/ $(\rho_{si}/\rho_{s1})^{-2.7}$ Versus the Cement/Sawdust Ratio.

4.4 Drying Shrinkage of the Sawdust Concrete

The drying shrinkage of the sawdust concrete as a functions of cement/sawdust ratio and 28 days bulk density of the concrete were shown in Figure-4.4.1 and Figure-4.4.2 respectively. It was observed that the drying shrinkage decreased when the cement/sawdust ratio increased and bulk density of the concrete increased. The concrete made with No.2 sawdust had its drying shrinkage decreased from 0.5% to 0.1% as the cement/sawdust ratio increased from 2 to 12. The concrete made with No.1 sawdust had its drying shrinkage decreased from 0.52% to 0.1% as the cement/sawdust increased from 3 to 13. When comparing the drying shrinkage, the concrete made with No.2 sawdust had overall lower values than the concrete made with No.1 sawdust. The result indicated the drying shrinkage of the sawdust concrete was high.

4.5 Thermal Conductivity

The results of thermal conductivity of concrete made with No.1 sawdust and cement measured based on a constant mean temperature of about 25 °C and temperature differential at about 14 °C for 28 days bulk density was shown in Figure 4.5.1. The results of the thermal conductivity measured based on the same 28 days bulk density (862.667 Kg/m^3) and

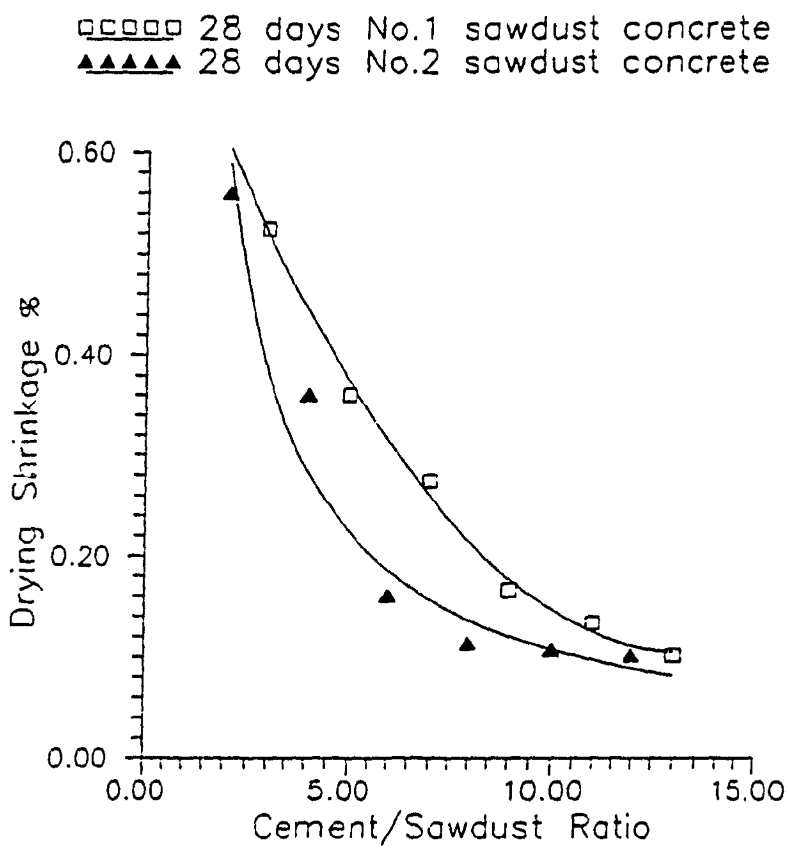


Figure 4.4.1. Drying Shrinkage of the Concrete Versus Cement/Sawdust Ratio.

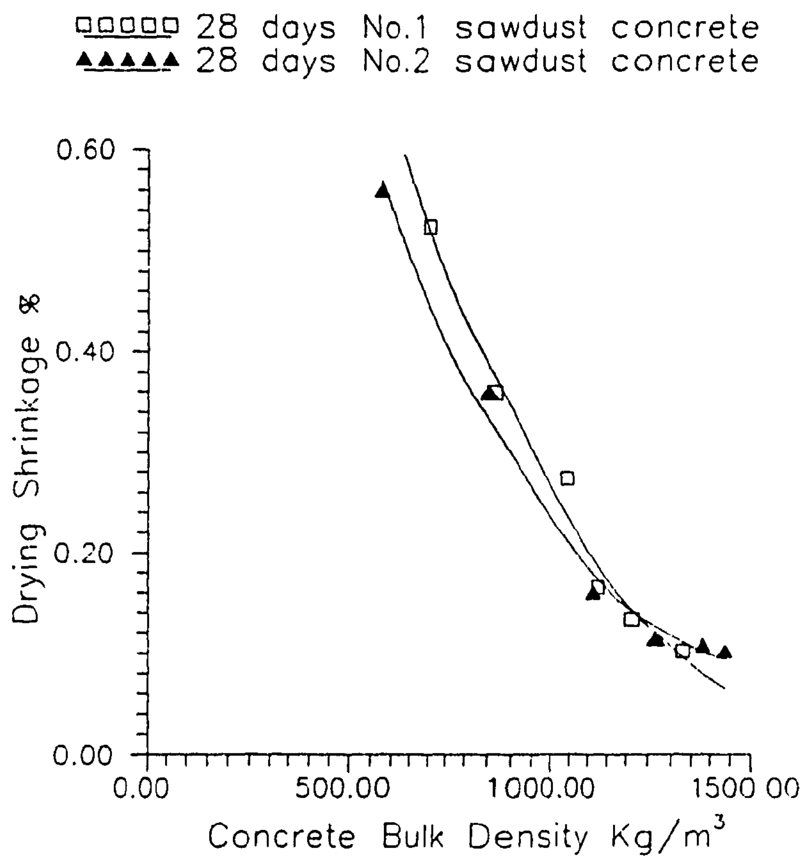


Figure 4.4.2. Drying shrinkage of the Concrete Versus 28 Days Bulk Density of Sawdust Concrete.

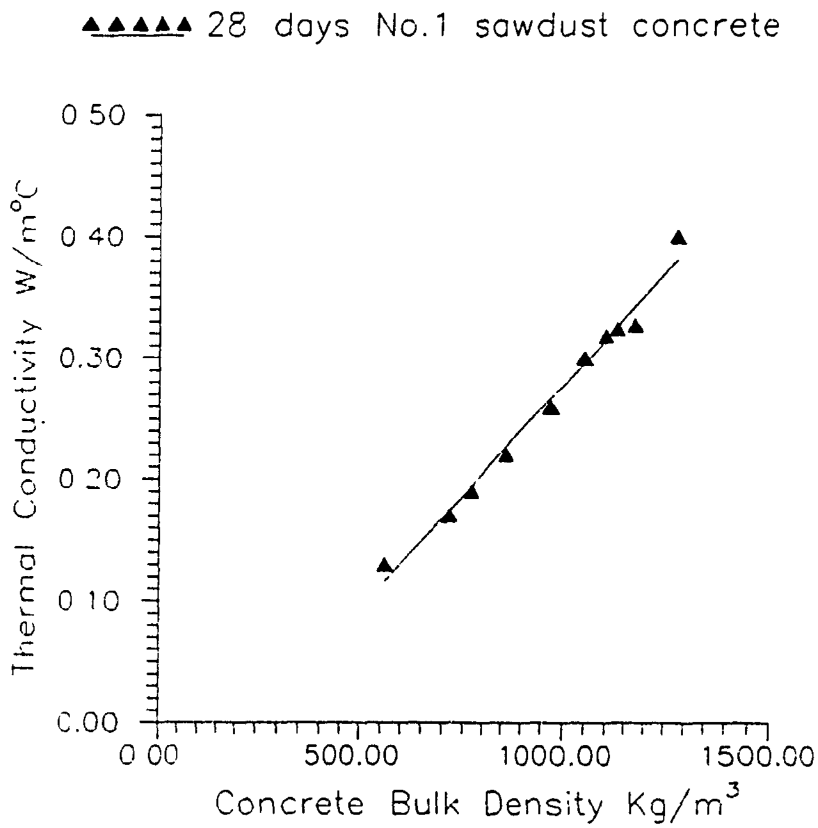


Figure-4.5.1 **Relationship Between the Thermal Conductivity and 28 Days Bulk Density of the Concrete at Mean Temperature of 25 °C and Temperature Differential at 14 °C for the Concrete Made With No.1 Sawdust.**

temperature differential at about 14 °C for different mean temperature is shown in Figure 4.5.2. It was observed that the thermal conductivity of the concrete made with No.1 sawdust ranged from 0.13 W/m°C to 0.4 W/m°C. and the thermal conductivity increased with 28 days bulk density in a range of 569.13 to 1289.1 Kg/m^3 at the mean temperature about 25 °C and the temperature differential about 14 °C. It only increased slightly with mean temperature in a range of 15 °C to 45 °C at same 28 days bulk density and temperature differential. The result means that the thermal conductivity of the concrete made with No.1 sawdust is low.

4.6 Durability of the Concrete

The compressive strength of the concrete after and without freezing-thawing cycling treatment for 300 cycles within the temperature range of -17.8 to 4.4 °C were measured. The durability coefficient which is a ratio of the compressive strength of concrete after freezing-thawing cycling treatment to the compressive strength without treatment was calculated as shown in Table-4.6.1 and Table-4.6.2. The results showed that the sawdust concrete had high durability coefficients. Figure-4.6.1. showed that the compressive strength of the sawdust concrete after the freezing-thawing cycling treatment was essentially unchanged as compared with those without the

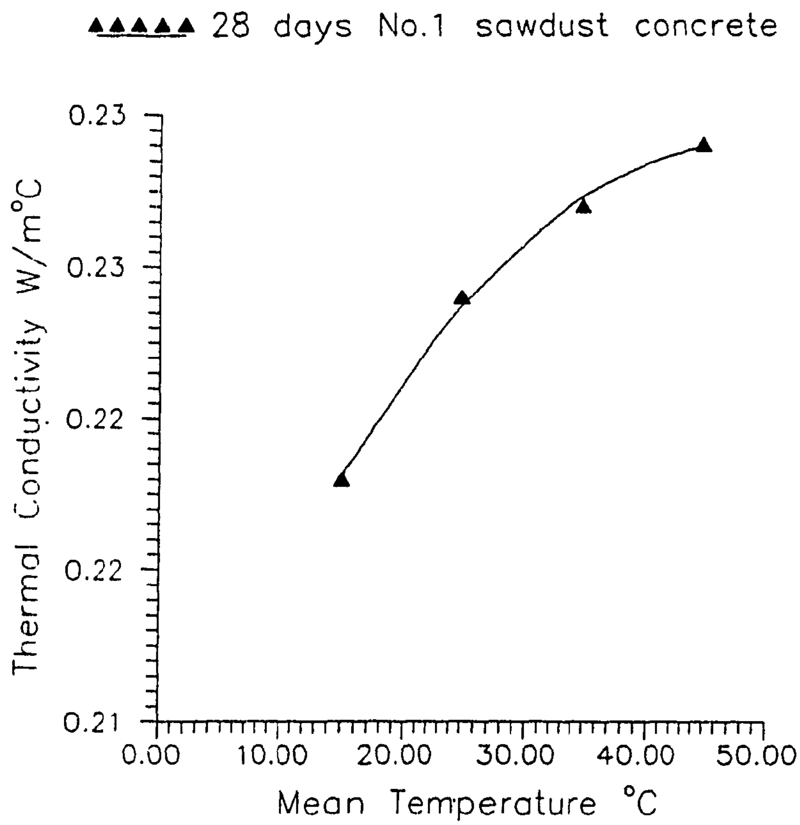


Figure-4.5.2. Relationship Between Thermal Conductivity and Mean Temperature at the 28 Days Bulk Density (862.67 Kg/m³) and Temperature Differential of 14°C for the Concrete Made With No.1 Sawdust.

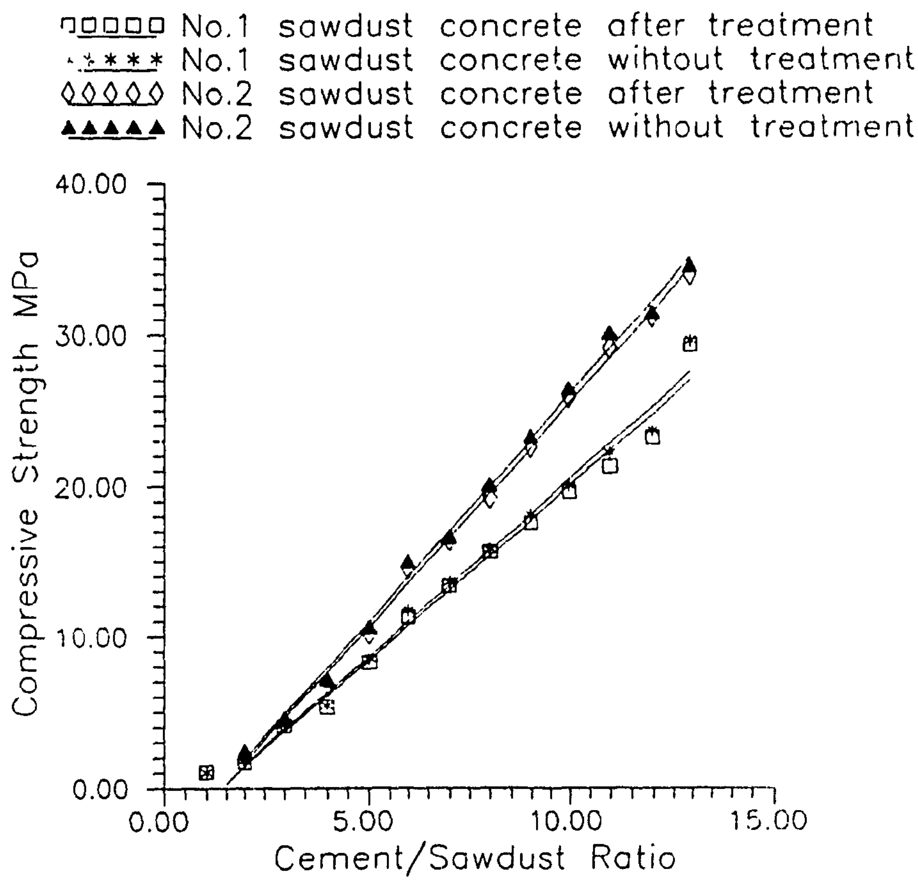


Figure-4.6.1. Compared the Compressive Strength After Freezing-Thawing Cycling Treatment With the Compressive Strength Without the Treatment.

Table-4.6.1. Variation of Durability Coefficient of the Concrete Made With No.1 Sawdust, Which is the Ratio of the Compressive Strength After Freezing-Thawing Cycling Treatment to the Compressive Strength Without Treatment as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	Durability %	S.D.	C.O.V. %
1.0	0.94	0.009	0.95
2.0	0.95	0.00[illegible]	0.84
3.0	0.97	0.009	0.92
4.0	0.98	0.008	0.82
5.0	0.97	0.008	0.82
6.0	0.96	0.013	1.30
7.0	0.98	0.006	0.61
8.0	0.99	0.012	1.20
9.0	0.97	0.005	0.52
10.0	0.98	0.007	0.71
11.0	0.96	0.008	0.83
12.0	0.98	0.006	0.61
13.0	0.99	0.009	0.91

S.D. = Standard Deviation
C.O.V. = Coefficient of Variation

Table-4.6.2. Variation of Durability Coefficient of the Concrete Made With No.2 Sawdust, Which is the Ratio of the Compressive Strength After Freezing-Thawing Cycling Treatment to the Compressive Strength Without Treatment as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	Durability %	S.D.	C.O.V. %
2.0	0.95	0.007	0.73
3.0	0.95	0.009	0.95
4.0	0.97	0.005	0.52
5.0	0.96	0.006	0.63
6.0	0.97	0.01	1.03
7.0	0.99	0.008	0.80
8.0	0.96	0 006	0.63
90	0.97	0.011	1.13
10.0	0.98	0.005	0.51
11.0	0.97	0.007	0.72
12.0	0.99	0.006	0.60
13.0	0.98	0.007	0.71

S.D. = Standard Deviation
C.O.V. = Coefficient of Variation

treatment. It indicated that the sawdust concrete was capable to withstand environmental temperature change without catastrophic failure.

4.7 Compressive Strength of the Concrete

The average results of 7 days and 28 days compressive strength have been measured. It was observed that the compressive strength of the sawdust concrete increased when the cement/sawdust ratio increased and the compressive strength increased when the curing age increased from 7 days to 28 days based on same cement/sawdust ratio as shown in Figure-4.7.1. The compressive strength of concrete made with No.1 sawdust for curing ages of 7 days and 28 days increased from 0.08 MPa to 20.8 MPa and from 0.8 MPa to 28.01 MPa respectively when the cement/sawdust ratios increased form 1 to 13. The compressive strength of the concrete made with No.2 sawdust for curing ages of 7 days and 28 days increased from 1.41 MPa to 27 MPa and 2.08 MPa to 35 MPa respectively when the cement/sawdust ratios increased from 2 to 13.

It was also seen that the concrete made with higher sawdust bulk density had higher compressive strength compared with the concrete made with lower sawdust bulk density based on the same cement/sawdust ratio. The compressive strength of

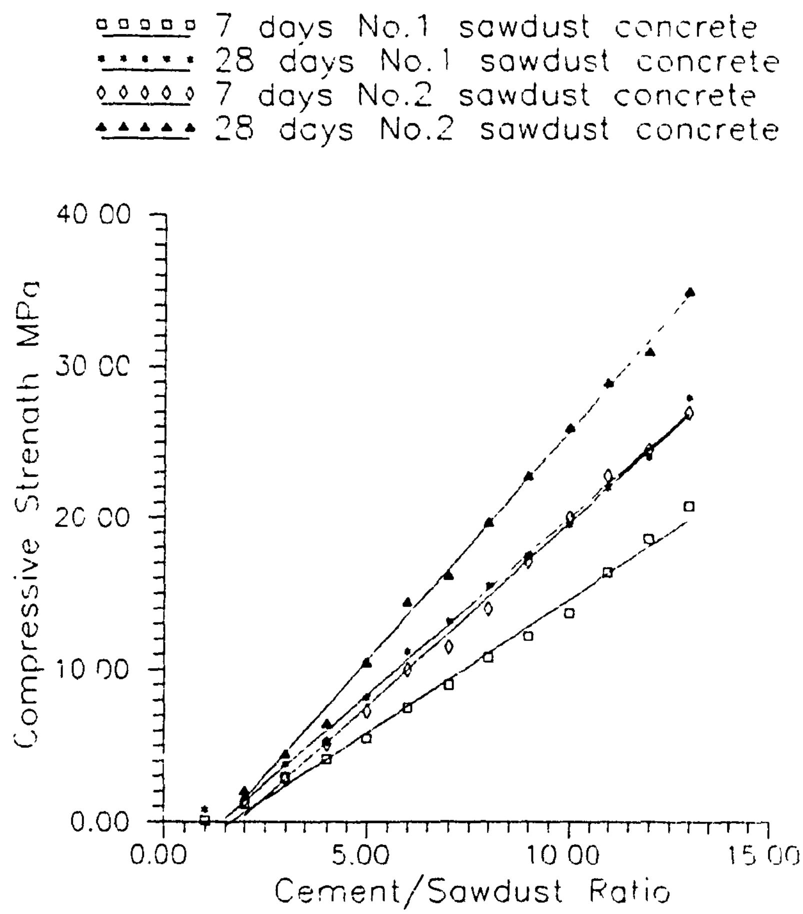


Figure-4.7.1. Compressive Strength Versus Cement/Sawdust Ratio.

the concrete also increased when the bulk density of the concrete increased. The compressive strength made with No.2 sawdust was slightly lower than the concrete made with No.1 sawdust based on the same bulk density of the concrete was shown in Figure-4.7.2. It indicated that the compressive strength of sawdust concrete is related to the cement/sawdust ratio and the bulk density of sawdust but is also related to the bulk density of the concrete.

The relationship between compressive strength and cement/sawdust ratio, sawdust bulk density and curing age (7, 28 days) was determined by dimensional analysis and regressional analysis which was given in the Dimensionless Equation-4.7 and it was also illustrated in Figure-4.7.3. It showed that the ratio of $C.S./(\rho_{s1}*[\rho_{s1}/\rho_{si}]*V^2*[D_j/D_{28}]^{0.232})$ is highly correlated with the ratio of C/S (correlation coefficient $r^2 = 0.96$).

Dimensionless Equation-4.7 was shown as following:

$$C.S./(\rho_{s1}*[\rho_{s1}/\rho_{si}]*V^2*[D_j/D_{28}]^{0.232}) = -0.018 + 0.012(C/S) \qquad (4.7)$$

Where:

C.S. = Compressive strength MPa

V = Loading speed of the testing machine mm/min.

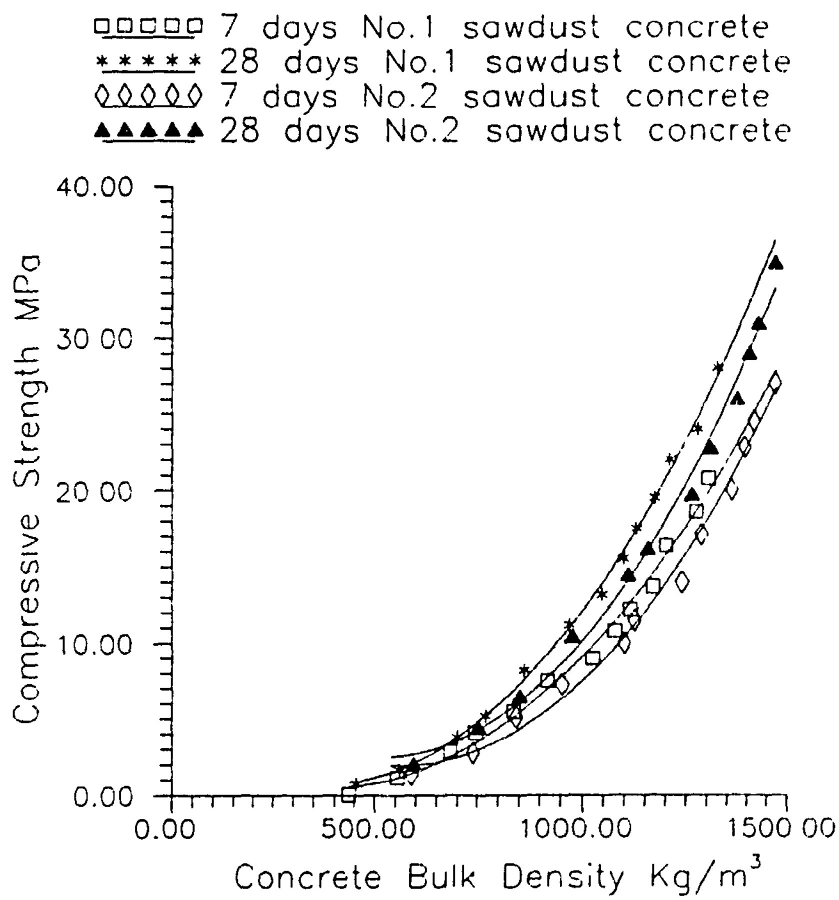


Figure-4.7.2. Compressive Strength Versus Bulk Density of the Concrete.

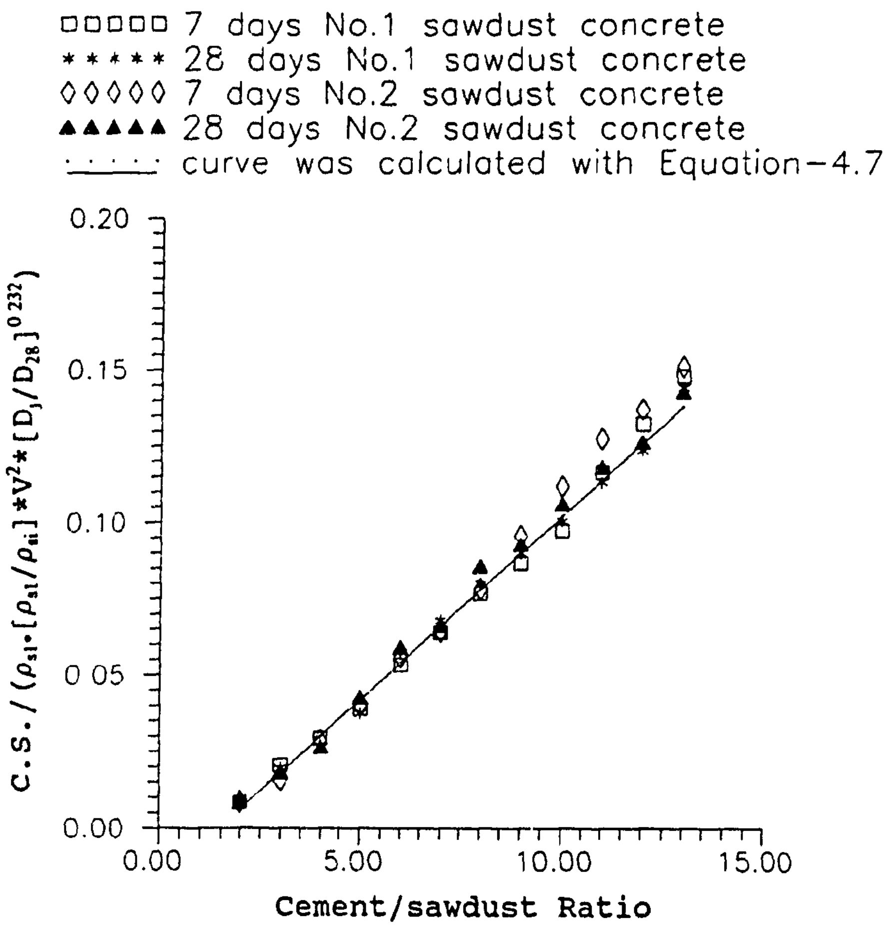


Figure-4.7.3. $C.S./(\rho_{s1}*[\rho_{s1}/\rho_{si}]*V^2*[D_j/D_{28}]^{0.232})$ **Versus the Cement/Sawdust Ratio.**

ρ_{si} = Sawdust bulk density Kg/m^3

(i = 1, 2; ρ_{s1} = 194, ρ_{s2} = 218)

D_j = Curing age (j = 7, 28) days

C/S = Cement/sawdust ratio

4.8 Bending Strength of the Concrete

The average results of bending strength for curing ages of 7 days and 28 days were observed to increased form 0.04 MPa to 3.6 MPa and from 0.06 MPa to 3.85 MPa respectively for the concrete made with No.1 sawdust when the cement/sawdust ratios increased from 1 to 13. Similarly it increased from 0.65 MPa to 4.46 MPa and 0.7 MPa to 4.72 MPa respectively for the concrete made with No.2 sawdust when the cement/sawdust ratios increased from 2 to 13. It was seen that the bending strength increased when the cement/sawdust ratio increased and increased when the curing age increased from 7 days to 28 days for the same cement/sawdust ratio from Figure-4.8.1. It was also seen that the bending strength of the concrete with higher sawdust bulk density was higher than the concrete with lower sawdust bulk density based on the same cement/sawdust ratio.

As with the compressive strength, the bending strength increased when the bulk density of the concrete increased, but

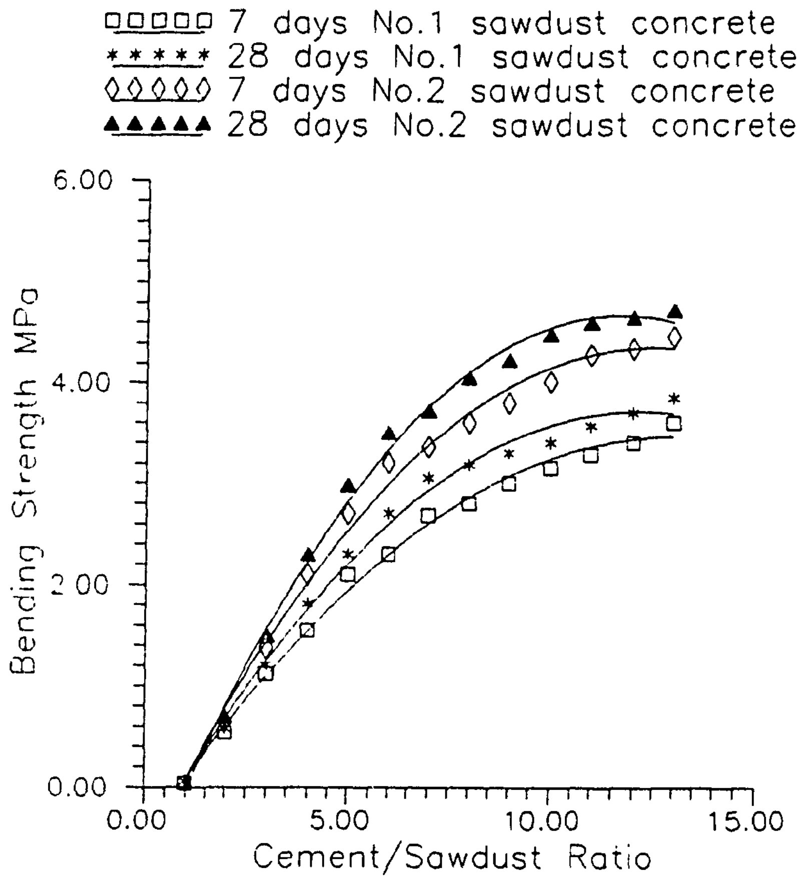


Figure-4.8.1. Bending Strength Versus Cement/Sawdust Ratio.

the bending strength of the concrete with higher sawdust bulk density was only slightly higher than the concrete made with lower sawdust bulk density based on same bulk density of the concrete as show in Figure-4.8.2. It also indicated the bending strength was related to the cement/sawdust ratio and the bulk density of the sawdust but was also related to the bulk density of the concrete.

The relationship between bending strength and cement/sawdust ratio, sawdust bulk density and curing age for 7 and 28 days was determined by dimensional analysis and regressional analysis which was given in Dimensionless Equation-4.8 and it also was illustrated in Figure-4.8.3. It showed that the ratio of $B.S./(\rho_{s1}*[\rho_{s1}/\rho_{si}]*V^2*[D_j/D_{28}]^{0.065})$ is highly correlated with the ratio of C/S (correlation coefficient $r^2 = 0.96$).

Dimensionless Equation-4.8 was shown in following:

$$B.S./(\rho_{s1}*[\rho_{s1}/\rho_{si}]*V^2*[D_j/D_{28}]^{0.065}) = -0.003 + 0.0034(C/S) - 0.00013(C/S)^2 \quad (4.8)$$

Where:

B.S. = Bending strength MPa

D_j = Curing age days

(j = 7, 28 days)

C/S = Cement/sawdust ratio

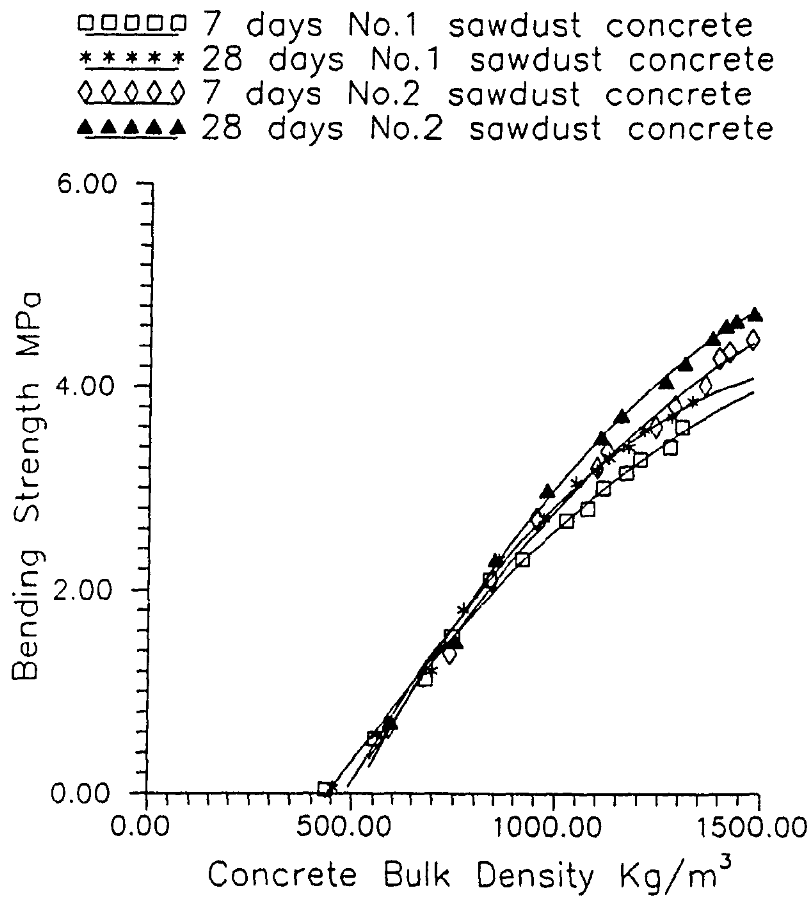


Figure-4.8.2. Bending Strength Versus Bulk Density of the Concrete.

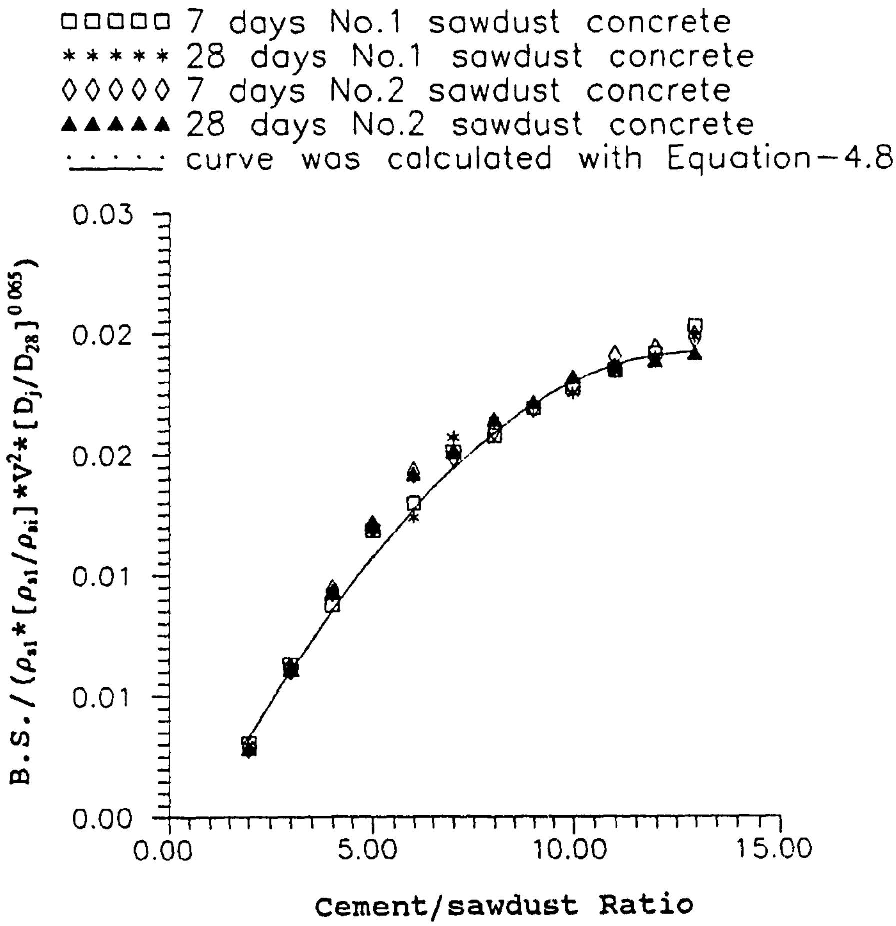


Figure-4.8.3. **B.S./$(\rho_{s1}*[\rho_{s1}/\rho_{si}]*V^2*[D_j/D_{28}]^{0.065})$ Versus the Cement/Sawdust Ratio.**

V = Loading speed of the testing machine mm/min.

ρ_{si} = Sawdust bulk density Kg/m^3

(i = 1, 2: ρ_{s1} = 194, ρ_{s2} = 218)

4.9 Summary

In summary, the sawdust concrete is light and its compressive strength and bending strength increase when the cement/sawdust ratio and bulk density of the concrete increase. It has low thermal conductivity and high durability, but it is with high water absorption and drying shrinkage.

In comparing the mechanical properties and thermal properties, the concrete made with No.2 sawdust is better than the concrete made with No.1 sawdust based on same cement/sawdust ratio. This is due to the higher bulk density of the No.2 sawdust. But, the mechanical properties of the concrete made with No.2 sawdust are almost the same when compared with the concrete made with No.1 sawdust for the same bulk density of the concrete. Therefore, it is beneficial to make the concrete with No.2 sawdust. For the same bulk density of the concrete, it can save cement material and obtain the same mechanical properties and better thermal properties as compared with the concrete made with No.1 sawdust.

CHAPTER 5

GENERAL DISCUSSION

The lightweight concretes can be classed as low density concrete, moderate strength concrete, and structural concrete.

Following the America Concrete Institute (ACI) Standard [54,55,56,57], the low density concrete is employed chiefly for insulation purposes with low seldom exceeding 800 kg/m^3, its heat insulation values are high, ranging from 0.11 W/m°C to 0.2 W/m°C, compressive strength are low, ranging from about 0.48 MPa to 6.98 MPa. It is usually used in the field of roof deck, for industrial and commercial building or for precast concrete floor, roof and wall units.

The moderate strength concretes have oven-dry densities greater than 800 Kg/m^3 and less than 1900 Kg/m^3. Its compressive strength range is approximately from 7 MPa to 17.24 MPa and insulation values are intermediate about from 0.2 W/m°C to o.75 W/m°C. Those concretes in the lower portion of this density range are generally used for thermal and sound insulation fill for roof, wall, and floors. At the higher densities they are used in cast-in-place wall, floors and roofs, and also for precast elements such as wall and floor panels.

For the structure concretes, the minimum compressive strength is 17.24 MPa and the density dose not exceed 1920 Kg/m^3. It has many and varied applications: multistorey building frames and floors, curtain wall, shell roofs folded plates, bridges, prestressed or precast elements of all types.

The various classifications of the lightweight concrete are summarized in Figure-5.1 [58]. From this figure, it can be seen that the developed lightweight concrete based on Maple sawdust-cement can be classified as the low density concrete when the cement/sawdust ratios were from 1 to 3 or as the moderate strength concrete when the cement/sawdust ratios were higher than 3.

Table-5.1 presents a summary of properties of different lightweight concretes [59], and Table-5.2 shows the values of the concrete made with soft wood sawdust which was reported by Parker in 1947 [4]. Comparing the results of the concrete made with Maple tree sawdust with those values given in Table-5.1, Table-5.2 and the requirement for the lower density concrete and moderate strength concrete, some discussions follow.

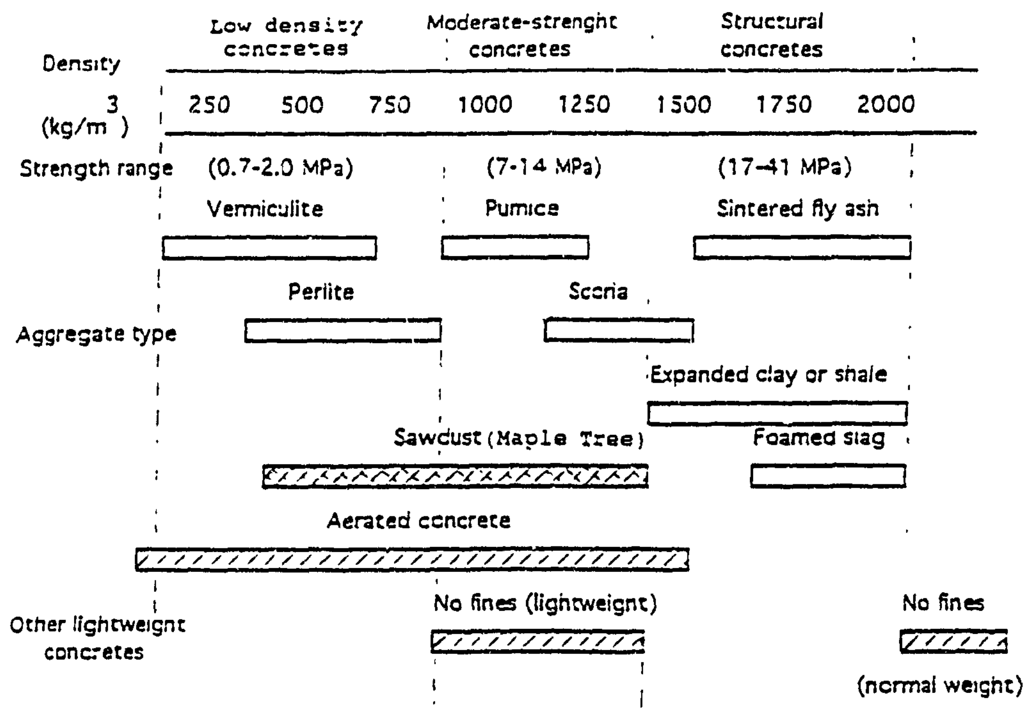


Figure-5.1 Classification of Lightweight Concrete [58].

Table-5.1, A Summary of Properties of Different Lightweight Concrete [59].

Type of Concrete	Bulk Density of Aggregate Kg/m^3	Density of Concrete Kg/m^3	Compressive Strength MPa	Drying Shrinkage %	Thermal Conductivity W/mk
Aerated	pfa 950 sand 1600	750 900	3 6	0.07 0.07	0.19 0.22
Auto-claved aerated	-	800	4	0.08	0.25
Foamed Slag	Fine 900 coarse 650	1700- 1800 2100	7-21 41	0.04- 0.05 0.06	0.45- 0.69 0.76
Rotary-Kiln Expanded Clay	Fine 700 Coarse 400	650-1000 1100 1200 1300	3 - 4 14 17 19	- 0.055 0.06 0.07	0.17 0.31 0.38 0.40
Rotary-kiln Expanded Clay With Natural Sand	400	1350- 1500	17	-	0.57
Sinter-Strand Expanded Clay	Fine 1050 Coarse 650	1500 1600	24 31	0.06 0.075	0.55 0.61
Rotary-Kiln Expanded Slate	Fine 950 Coarse 700	1700 1750	28 35	0.04 0.045	0.61 0.69
Sintered Pulver-ized Fuel Ash	Fine 1050 Coarse 800	1490 1500 1540 1570	20 25 30 40	0.03 0.03 0.035 0.04	- - - -

pfa = pulverized fuel ash (fly ash).

Table-5.1 Continue

Type of Concrete	Bulk Density of Aggregate Kg/m³	Density of Concrete Kg/m³	Compressive Strength MPa	Drying Shrinkage %	Thermal Conductivity W/mk
Sintered Pulverized Fuel Ash With Natural Sand	Coarse 800	1670 1700 1750 1790	20 25 30 40	0.03 0.03 0.035 0.04	- - - -
Pumice	500-800	1200 1250 1450	14 19 29	0.12 0.1 -	- 0.14 -
Exfoliated Vermiculite	65-130	300-500	2	0.3	0.1
Perlite	95-130	-	-	0.2	0.05

Table-5.2. Some Properties of the Concrete Made With Softwood Sawdust [4].

Mix Proportions (by Volume)	Dry Density of Concrete Kg/m^3	Compressive Strength at 28 days MPa	Drying Shrinkage %	Thermal Conductivity W/mk
1:1	1600	34.5	0.25	-
1:2	1200	12.1	0.35	0.3
1:3	880	4.8	0.5	0.3
1:4	640	1.7	0.5	0.2

5.1. Compressive Strength

It was observed that the concrete made with Maple sawdust had higher compressive strength than some other lightweight concretes which were shown in Table-5.1 [59], such as Aereted, Foamed Slag, Sinted-Strand Expanded, Pumice and Vermiculite concrete, and the concrete made with softwood sawdust which was shown in Table-5.2 [4] based on the same bulk density of concrete. The results were shown in Figure-5.1.1. and Figure-5.1.2. respectively. It can be seen that the compressive strength of the concrete made with Maple sawdust can meet the requirement for the low density concrete when the cement/sawdust ratio is from 1 to 3 and for the moderate strength concrete when the cement/sawdust ratio is greater than 3.

5.2 Bending Strength

The bending strength is also a measure of the tensile strength of concrete. For the concrete used for insulation purposes, this is not required. For the structure purposes, the bending strength values generally range about from 2.3 MPa to 5 MPa [54]. So the concrete made with Maple sawdust can also meet these requirements when the cement/sawdust ratio is greater than 4 if it is used for structure purpose.

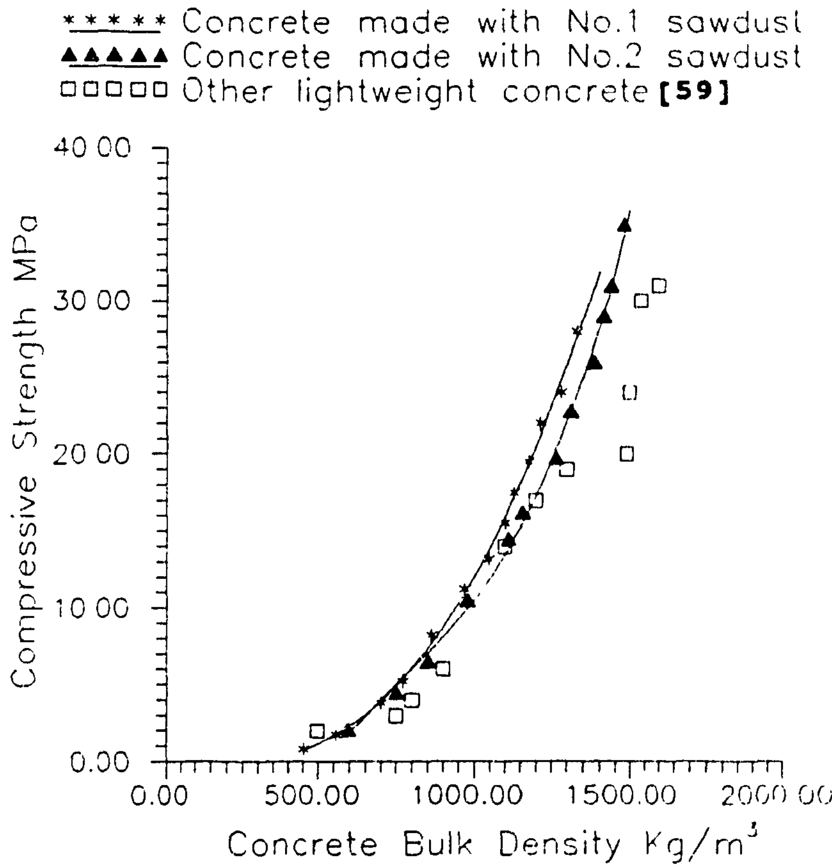


Figure-5.1.1. Compared Compressive Strength of the Concrete Made With Maple Sawdust With Other Lightweight Concrete which were shown in Table- .1 [59].

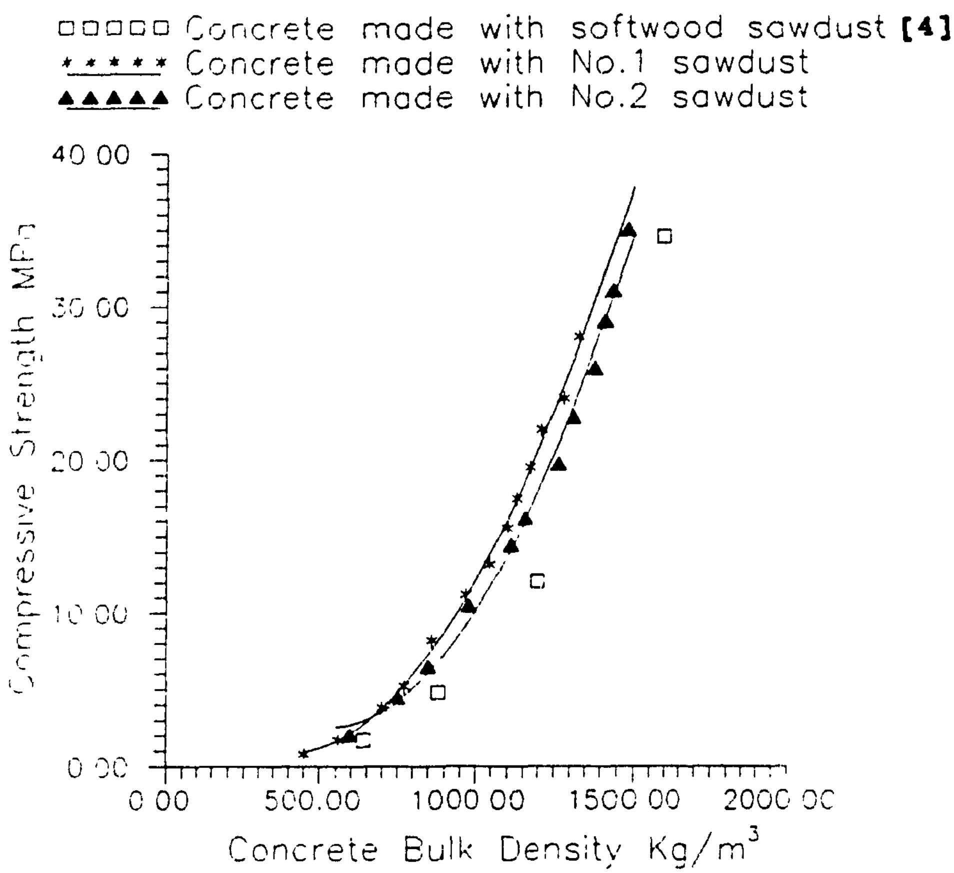


Figure-5.1.2 **Compared Compressive Strength of the Concrete Made With Maple Sawdust With the Concrete Made With Softwood Sawdust which was shown in Table-5.2 [4].**

5.3. Thermal conductivity

The thermal conductivity is also very important for building materials. The lower the thermal conductivity is, the better the insulation of the walls and other components of the building. This results in smaller changes in temperature inside the house due to external temperature changes. The thermal conductivity of the concrete made with Maple sawdust is nevertheless very satisfactory and it is lower than the normal concrete (1.2-3.0 W/mk), and is nearly as the same as other lightweight concretes which were shown in Table-5.1 [59], such as Aerated, Autoclaved Aerated, Foamed Slag and Rotary-Kiln Expanded Clay concrete. The result was shown in Figure-5.3.1. It can meet the requirement of the low density concrete (0.11-0.2 W/mk) when the cement/sawdust ratio is lower than 3 and can also meet the requirement of the moderate strength concrete (0.2-0.75 W/mk) when the cement/sawdust ratio is higher than 3. Therefore the concrete made with Maple sawdust can be used as insulation material for building.

5.4. Drying Shrinkage

Drying shrinkage is mainly affected by the quantity of cement paste in the concrete and the type of aggregate used. Generally, the lower the strength of concrete is, the higher

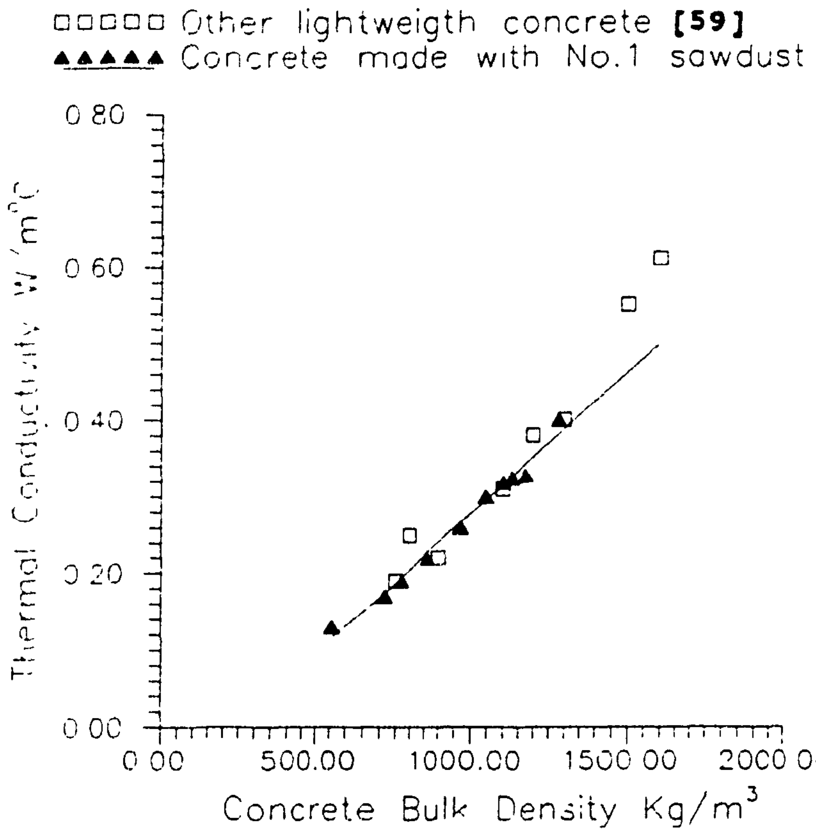


Figure-5.3.1 Compared Thermal Conductivity of the Concrete Made With Maple sawdust With Other Lightweight Concrete which were shown in Table-5.1 [59].

the drying shrinkage is. For the low density concrete which has high shrinkage about from 0.1 to 0.6 %, it is not usually critical. This is because the primary function is for roof deck insulation and fill applications. For their structural use, the drying shrinkage should be considered. Results have shown that the drying shrinkage of the concrete made with Maple sawdust is high, almost about 10 times as great as other lightweight concrete with the expection of pumice, Exfoliated Vermiculite and Perlite concrete which were shown in Table-5.1 [59]. Concrete with steam curing and the addition of sand has been used to reduce the drying shrinkage. The steam curing method is more expensive than the addition of sand. Therefore, the effect of sand addition on the drying shrinkage of the concrete was investigated in this research program.

5.5. Water Absorption and Durability

Generally, lightweight concretes have considerably higher water absorption values than the normal concretes because of they are somewhat porous. This is not considered to be of great importance in practice, since lightweight concrete exposed to the weather is not generally used without a suitable protective rendering. The water absorption of concrete made with the Maple sawdust is higher than other some lightweight concrete. However, high absorption dose not necessarily indicate that the concrete will have poor durability. Results have also shown that the concrete made with Maple sawdust have high durability. After 300 freezing-thawing cycling treatments it was capable of withstanding the environmental temperature change without catastrophic failure.

5.6 Summary

In summary, the developed new lightweight concrete made with Maple sawdust can be classed as the low density concrete when the cement/sawdust ratios is from 1 to 3 or as the moderate strength concrete when the cement/sawdust ratios are higher than 3. Compared with other lightweight concrete, it has higher compressive strength with lower thermal conductivity based on same density of concrete. Though the drying shrinkage and the water absorption of the concrete is high, it maintains high durability. Its mechanical and thermal properties can meet the requirement for the low density concrete and the moderate strength concrete. The sawdust concrete can be used for residential and commercial building construction for energy conservation, such as jointless floor finishes, precast floor tiles, wall and roof units.

CHAPTER 6

THE EFFECT OF CHEMICAL ADDITIVE ON STRENGTH OF THE CONCRETE AND THE EFFECT OF SAND ON THE DRYING SHRINKAGE AND WATER ABSORPTION OF THE CONCRETE

From the literature review, it was seen that extractives from wood, namely sugars and tannins, were interfering with the proper setting of cement. Unless this interference was somehow overcome, products of low mechanical strength were obtained. However, different kinds of wood species will get different effect on the setting of cement. Results indicated that the lower cement/wood ratio reflected more effect of wood on the setting of cement than the higher cement/wood ratio [60].

During preparation of the samples which were made with Maple tree sawdust and cement for cement/sawdust ratio less than 4, it was seen that the samples were difficult to remove from the mold into water after the samples were cured in air for 24 hours. This was since the samples were softer and with low bonding strength between wood sawdust and cement.

Numerous chemical additives were tried and used as a means of overcoming this problem. Calcium chloride was found to be the most effective additive on different wood species (61). Therefore, in this research program, the industry standard calcium chloride was selected to be as chemical additive. The comparison of compressive strength and bending strength between the concrete with calcium chloride and the concrete without calcium chloride is to investigate the effect of the additive on the concrete strength.

In addition, the results have shown that the concrete made with Maple tree sawdust and cement had high drying shrinkage and water absorption. The addition of sand would have reduced the drying shrinkage and water absorption, while overall materials costs were reduced [61]. So the industry standard sand of Canada was used to investigate the effect of sand on the drying shrinkage and water absorption of concrete in this research program.

6.1 Materials

For the investigation, the No.2 Maple tree sawdust was selected to mix with portland cement and water. The three percent solid content calcium chloride (based on cement weight) in liquid form was added to the mixture to investigate the effect of additive on the concrete strength, and the addition of sand was maintained at the ratio of sand to cement (2:1) by weight to add to the mixture to investigate the effect of sand on drying shrinkage and water absorption of the concrete.

6.2 Specimens Preparation

The experimental procedures for specimen preparation was the same as described in Section 3.3. For the specimen prepared to investigate the effect of additive on the concrete strength, the only difference was that the calcium chloride was first dissolved in water and then the solution was used to mix cement (step 2 in Section 3.3).

For the specimens prepared to investigate the effect of sand on the drying shrinkage and water absorption of the concrete, the difference was that sand and sawdust were added to the cement paste at same time (step 4 in Section 3.3) besides the calcium chloride that was added to the mixture of sawdust and cement.

6.3 Testing Procedures

The compressive strength, bending strength, water absorption, drying shrinkage and bulk density of the concrete with calcium chloride and the concrete with sand and calcium chloride were measured. The testing procedures were the same as described in Section 3.4. Six specimens for each ratio of cement/sawdust from 2 to 4 were tested and the average results were calculated.

6.4 Experimental Results

6.4.1 Calcium Chloride Effect on the Mechanical Strength of the Concrete

The average results of mechanical strength and some physical properties of the concrete made with calcium chloride were obtained for cement/sawdust ratios from 2 to 4. The comparison of compressive strength, bending strength, water absorption, drying shrinkage and bulk density between the concrete with calcium chloride and the concrete without calcium chloride was listed in Table-6.4.1.1.

It can be seen that the water absorption and drying shrinkage of the concrete with calcium chloride only slightly reduced when compared with the concrete without calcium chloride as shown in Figure-6.4.1.1 and 6.4.1.2. The compressive strength and bending strength of the concrete with

Table-6.4.1.1 Comparison of Mechanical Strength and Physical Properties Between the Concrete With Sand and calcium chloride, the Concrete With Calcium Chloride and the Concrete Without Sand and Calcium Chloride.

Composition by Weight S:C:Sand	$CaCl^2$ % Based on Cement Weight	Bulk Density Kg/m^3	C.S. MPa	B.S. MPa	W.A. %	D.S. %
1:2:0	0	595.0	2.38	0.70	73.73	0.560
1:2:0	3%	760.0	5.12	2.23	65.46	0.520
1:2:4	3%	995.6	2.40	0.72	37.21	0.271
1:3:0	0	752.0	4.57	1.50	46.10	-
1:3:0	3%	900.0	9.26	3.05	44.18	0.410
1:3:6	3%	1242.0	6.84	1.80	25.35	0.172
1:4:0	0	850.0	8.41	2.30	36.00	0.360
1:4:0	3%	1016.0	13.40	3.63	32.83	0.340
1:4:8	3%	1390.1	11.87	2.90	18.72	0.145

S:C:Sand = Sawdust : Cement : Sand
C.S. = Compressive Strength
B.S. = Bending Strength
W.A. = Water Absorption
D.S. = Drying Shrinkage

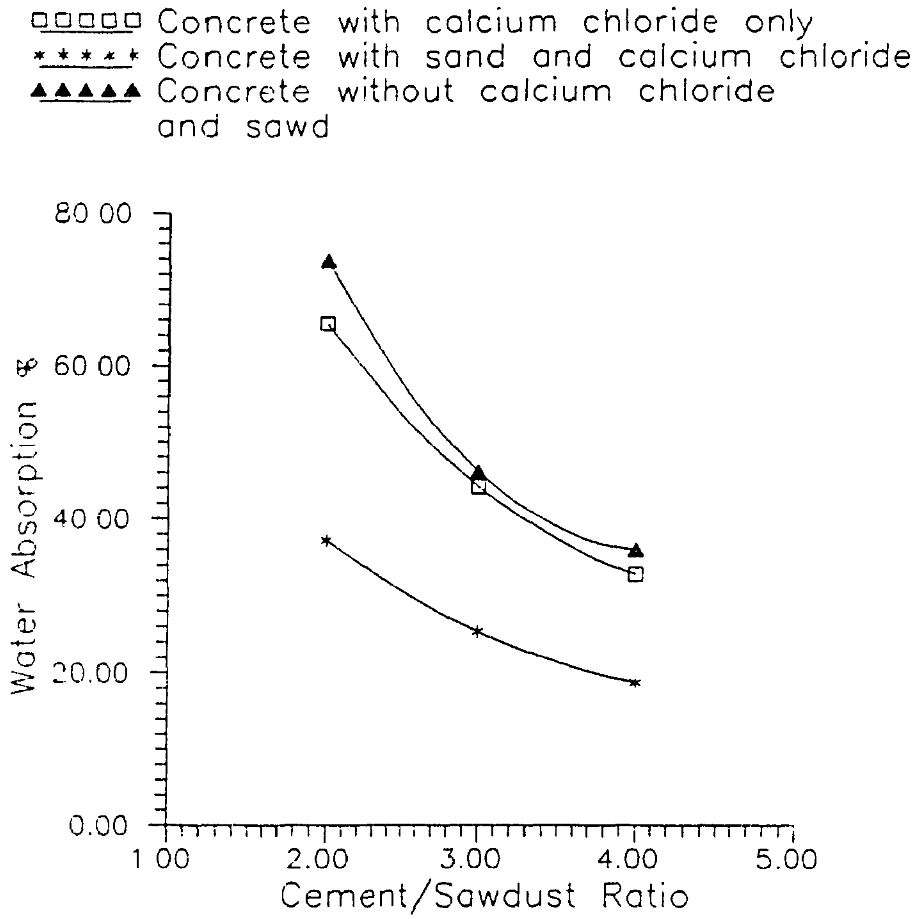


Figure-6.4.1.1 The Effect of Calcium Chloride and Sand on the Water Absorption Soaking in Water for 48 hours of the Concrete.

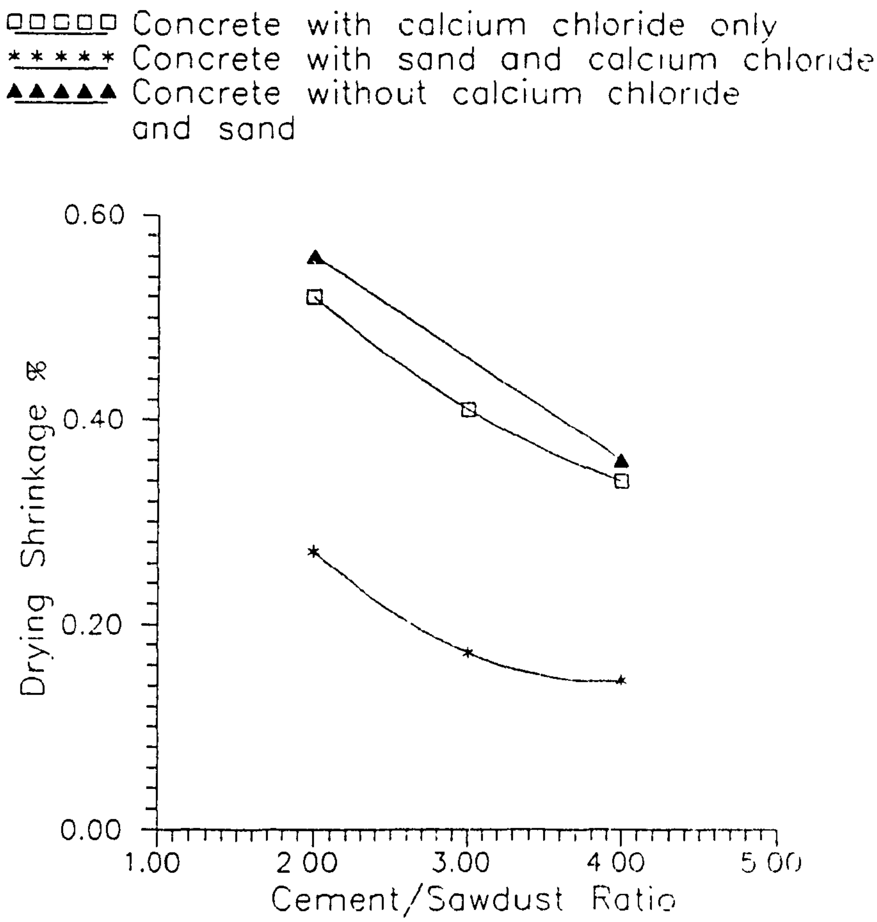


Figure-6.4.1.2 The Effect of the Calcium Chloride and Sand Addition on the Drying Shrinkage of the Concrete.

calcium chloride increased markedly when compared with the concrete without calcium chloride based on same cement/sawdust ratio as shown in Figure-6.4.1.3 and 6.4.1.4. It was seen that the specimens with calcium chloride were easy to remove from the molds into the curing water after curing the specimens in air for 24 hours. This was because the calcium chloride increased the early strength of the specimens so that the specimens were harder than the specimens without calcium chloride. It indicated the calcium chloride improved mechanical strength of the concrete.

In order to determine the compatibility of the wood-cement mixture, some researchers [16,19,20,29,38,40,62] proposed an inhibitory index formula using hydration time (the time required for the wood-cement mixture to attain its maximum hydration temperature). It was pointed out that the wood composition reduced the strength of mixture of wood-cement. This was since that the wood composition prolonged the hydration time and reduced the maximum hydration temperature as is shown in Figure-6.4.1.5 [62]. The additive to the mixture of wood and cement greatly increased the maximum hydration temperature and reduced hydration time as shown in Figure-6.4.1.6 [40], so that increased the compressive strength as shown in Figure-6.4.1.7 [63]. It was also observed that the bulk density of the concrete with calcium chloride increased based on same cement/sawdust ratio when compared

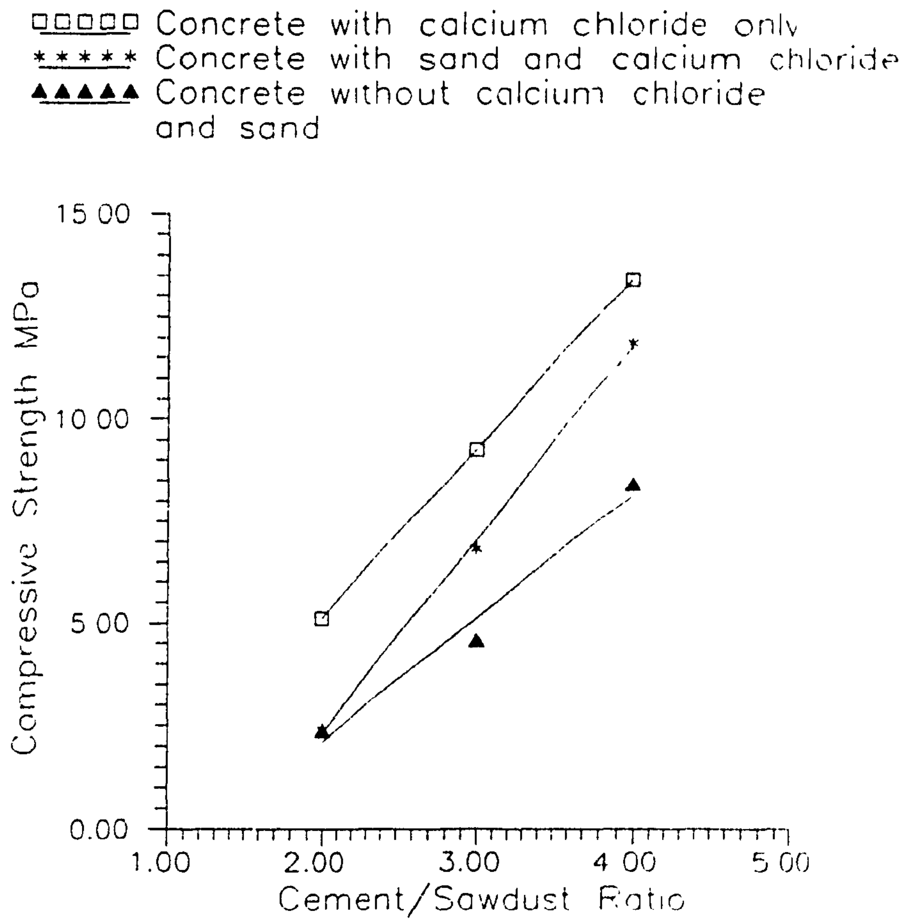


Figure-6.4.1.3 **The Effect of the Calcium Chloride and Sand Addition on the Compressive Strength of the Concrete.**

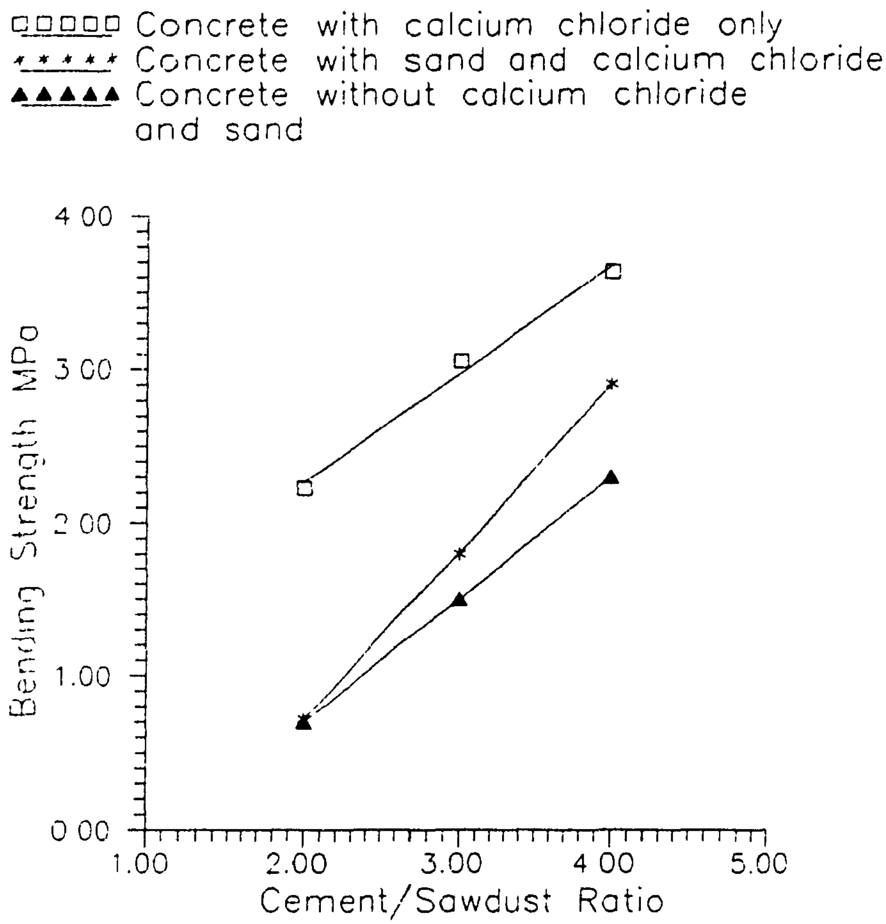
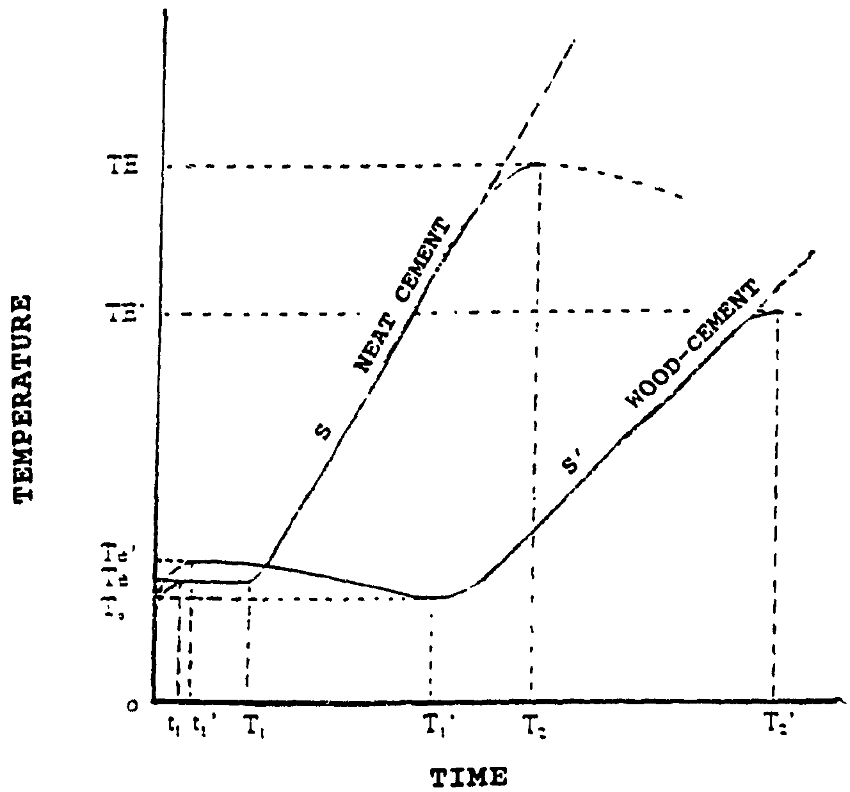


Figure-6.4.1.4 **The Effect of the Calcium Chloride and Sand Addition on the Bending Strength of the Concrete.**



T_e = AMBIENT ROOM TEMPERATURE AT THE TIME OF MIXING
TE & TE' = MAXIMUM TEMPERATURE OF NEAT CEMENT AND WOOD-CEMENT, RESPECTIVELY
T_2 & T_2' = THE TIME TO REACH TE AND TE', RESPECTIVELY
S & S' = MAXIMUM SLOPE OF NEAT CEMENT AND WOOD-CEMENT, RESPECTIVELY

Figure-6.4.1.5 Schematic Representation of Typical Hydration Cure [62].

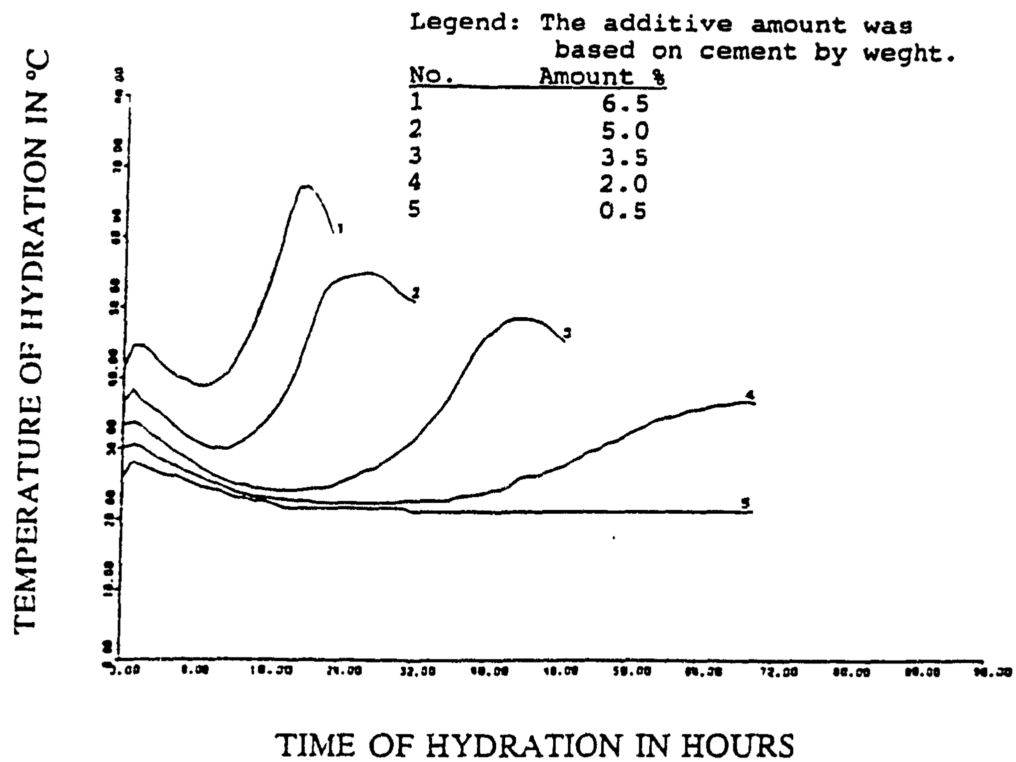


Figure-6.4.1.6 **The Influence of the Varying Amount of Chemical Additive on the Hydration of the Larch Wood Specie and Cement mixture [40].**

r^2 is correlation coefficient.

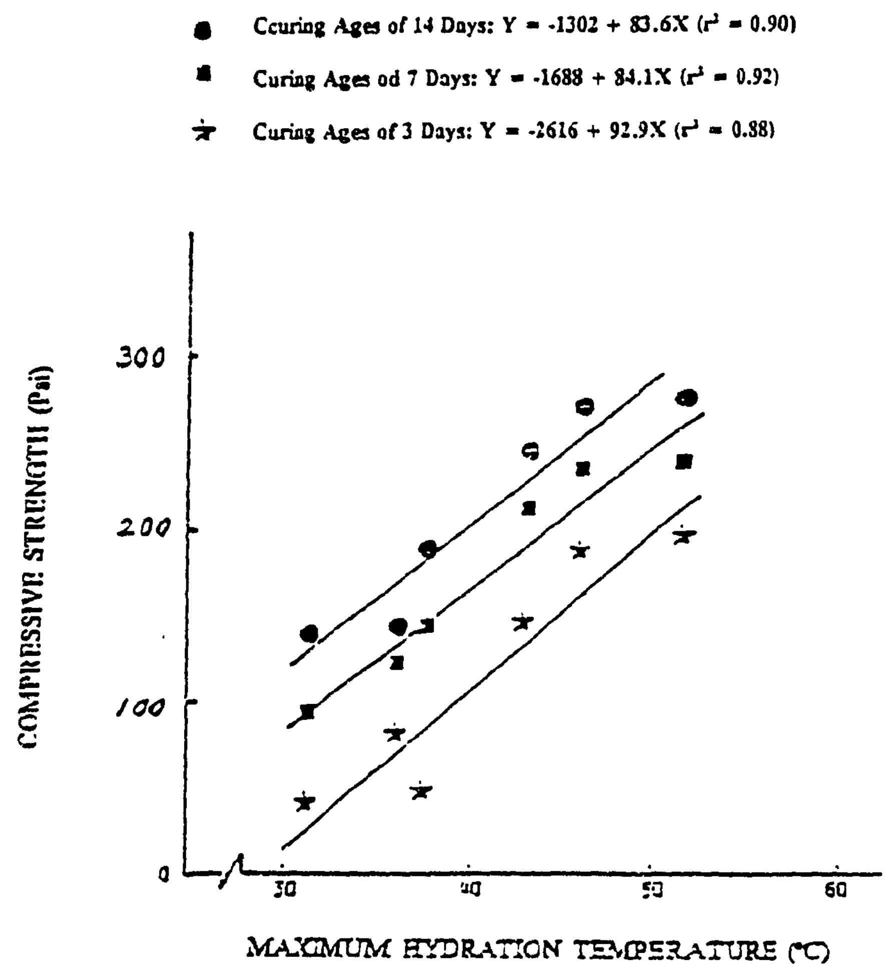


Figure-6.4.1.7 Relationship Between Compressive Strength and Hydration Temperature of Wood-Cement Mixture [63].

with the concrete without calcium chloride was shown in Figure-6.4.1.8.

6.4.2 Sand Effect on Drying Shrinkage and Water Absorption of the Concrete

The average results of mechanical strength and some physical properties of the concrete made with sand and calcium chloride were obtained for cement/sawdust ratios from 2 to 4. The compressive strength, bending strength, water absorption, drying shrinkage and bulk density of the concrete with sand and calcium chloride were also listed in Table-6.4.1.1.

It was observed that the addition of sand greatly reduced the water absorption and drying shrinkage of the concrete as shown in Figure-6.4.1.1 and 6.4.1.2. The bulk density of the concrete with sand was higher than the concrete without sand based on same cement/sawdust ratio as shown in Figure-6.4.1.8. The compressive strength and bending strength of the concrete with sand and calcium chloride was less than the concrete only with calcium chloride and was not much higher than the concrete without sand and calcium chloride based on same cement/sawdust ratio as shown in Figure-6.4.1.3 and 6.4.1.4.

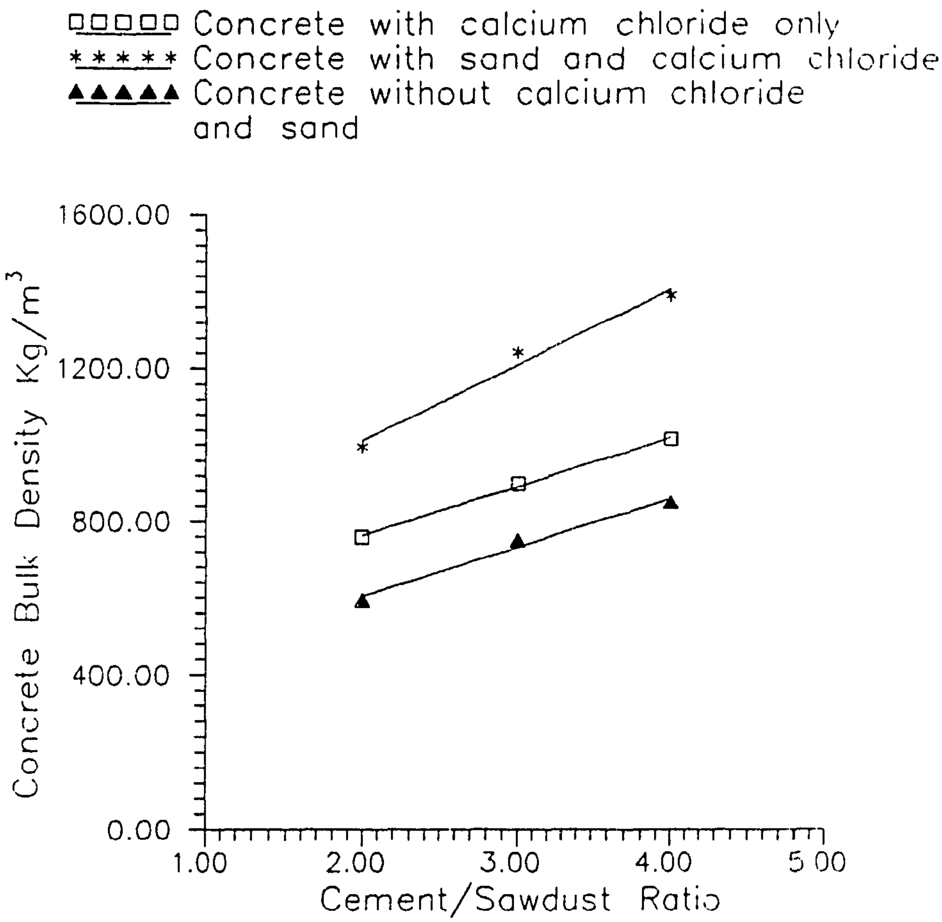


Figure-6.4.1.8 The Effect of the Calcium Chloride and Sand Addition on the Bulk Density of the concrete.

6.4.3 Summary

In summary, the addition of calcium chloride improves compressive strength and bending strength of the concrete. The sand addition reduces the drying shrinkage and water absorption but increases the bulk density of the concrete.

CHAPTER 7

CONCLUSION AND RECOMMENDATION FOR FURTHER WORK

7.1. Conclusions

The developed lightweight concrete based on sawdust-cement materials has been produced with two different sizes of Maple tree sawdust within the range of cement/sawdust ratios from 1 to 13. Basic mechanical and thermal properties of the lightweight concrete have been measured. Important variables such as sawdust bulk density, cement/sawdust ratio and curing age etc, and their influence on the properties of the concrete were found. From this investigation, the following conclusions can be drawn:

1. The concrete made with Maple sawdust is light. Its bulk densities range from 436 Kg/m^3 to 1486 Kg/m^3 when the cement/sawdust ratios range from 1 to 13. The density increases when the cement/sawdust ratio and the sawdust bulk density increase. When the curing age increases from 7 days to 28 days the bulk density increases slightly. The developed lightweight concrete based on sawdust-portland cement materials can be classified as the low

density concrete when the cement/sawdust ratios are from 1 to 3 or as the moderate strength concrete when the cement/sawdust ratios are higher than 3.

2. The compressive strength and bending strength of the concrete increase when the cement/sawdust ratio, curing age and bulk density of concrete increase. The concrete made with higher sawdust bulk density has higher compressive strength and bending strength than that made with lower sawdust bulk density for the same cement/sawdust ratio. They have, however, almost the same compressive strength and bending strength for the same concrete bulk density. The compressive strength and bending strength of the concrete range from 0.8 MPa to 34 MPa and 0.06 MPa to 4.7 MPa, respectively.

3. The thermal conductivity of the concrete is low. It ranges from 0.1 W/m°C to 0.4 W/m°C. It increases when the concrete bulk density increases. It increases slightly with an increase in the temperature.

4. The water absorption and the drying shrinkage are higher when compared with some other lightweight concrete. They decrease as the cement/sawdust ratio

and the concrete bulk density increase. The addition of sand reduces the drying shrinkage and the water absorption of the concrete but increases the bulk density of the concrete.

5. The investigation shows that the concrete has high durability. It indicates that the concrete is capable of withstanding environment temperature changes without catastrophic failure.

6. Adding calcium chloride improves the compressive strength and the bending strength of the concrete.

7. The developed lightweight concrete made with Maple sawdust has potential as a building material. It can be used as the low density concrete and the moderate strength concrete for building applications.

7.2 Recommendation for Further Work

In this project, the mechanical and thermal properties of the concrete made with Maple sawdust and portland cement (type 10) have been investigated. It is seen that the concrete made with Maple sawdust presents high water absorption and high beneficial effect on the drying shrinkage and the water absorption of the concrete. The addition of calcium chloride to the mixture of the cement and Maple tree sawdust improves the mechanical strength of the concrete. However, different kinds of sand with various quantities will effect the drying shrinkage and the water absorption of the concrete, and different wood species respond differently to various treatments. Therefore, in order to obtain the optimum concrete product, the following work is felt necessary:

1. To investigate the effect of different kinds of sand on the drying shrinkage and the water absorption of the concrete made with Maple sawdust and cement and to obtain optimum sand addition so that the concrete will have low drying shrinkage and water absorption, high mechanical strength, good thermal insulation, and economy.

2. To investigate the effects of different chemical additives and pretreatment methods of wood species (e.g. hot water pretreatment) on the mechanical strength of the concrete and the setting of the cement, and to find an optimal method for improvement of properties of the concrete.

3. To investigate the properties of the concrete made

with different types of cement and Maple sawdust.

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Appendix 1.

Calculation of the Compressive Strength Equation

$$C.S. = F/A$$

where:

C.S. = compressive strength (Pa)

F = maximum load (N)

A = average of the areas of t` upper and lower bearing surface of the specimen (m^2)

Appendix 2.

Calculation of the Bending Strength Equation

$$B.S. = 3FL_s/2W_fD^2$$

where:

B.S. = compressive strength (Pa)

F = maximum load (N)

L_s = span length (0.102 m)

D = the average depth of specimen at the point of fracture (m)

W_f = the average width of specimen at the point of fracture (m)

Appendix 3.

Calculation of the Bulk Density Concrete Equation

$$\rho_c = M/LWH$$

where:

ρ_c = bulk density of concrete (kg/m^3)

M = mass of dry specimen (Kg)

L = length of the specimen (m)

W = width of the specimen (m)

H = height of the specimen (m)

Appendix 4.

Calculation of the Water Absorption Equation

$$W.A._t = (G_t - G_d) \times 100\% / G_d$$

where:

$W.A._t$ = water absorption for t hours (%)

G_t = wet weight of specimen after soaking t hours (N)

G_d = dry weight of specimen (N)

Appendix 5.

Calculation of the Boiling Water Absorption Equation

$$B.W.A. = [(G_b - G_a)/G_d] \times 100\%$$

where:

B.W.A. = boiling water absorption (%)

G_b = weight of surface-dry sample in air after immersion and boiling (N)

G_a = weight of oven-dried sample in air (N)

Appendix 6.

Calculation of the Drying Shrinkage Equation

$$D.S. = (\Delta L/L) \times 100\%$$

where:

D.S. = linear drying shrinkage (%)

ΔL = change in the linear dimension of the specimen due to drying from a saturated condition to the equilibrium state (m)

L = dry specimen length (m)

Appendix 7.

Calculation of the Thermal Conductivity Equation

$$k = (Q/A_h) \times [1/(\Delta T/\Delta X_t + \Delta T/\Delta X_b)]$$

where:

k = average thermal conductivity of the two samples (W/m°C)

Q = total input to the main heater (W)

A_h = cross-sectional area of the main heater (m^2)

ΔT = temperature difference across the sample (°C)

ΔX_t = top sample thickness (m)

ΔX_b = bottom sample thickness (m)

Appendix 8.

Calculation of the Durability Coefficient Equation

$$D.C. = C.S._a / C.S._w$$

where:

D.C. = durability coefficient (between 0 to 1)

$C.S._a$ = compressive strength after freezing-thawing test (Pa)

$C.S._w$ = compressive strength without freezing-thawing test (Pa)

Appendix 9.

Calculation of the Correlation Coefficient Equation

$$r^2 = \frac{\left[\frac{1}{n}\sum_{i=1}^{n}(x_i - x)(y_i - y)\right]^2}{\frac{1}{n}\sum_{i=1}^{n}(x_i - x)^2 \frac{1}{n}\sum_{i=1}^{n}(y_i - y)^2}$$

r^2 = Correlation coefficient

X_i = An Individual Value

Y_i = An Individual Value

X = Average Value

Y = Average Value

Appendix 10.

The Average Values, Standard Deviation and Coefficient of Variation of Experimental Results in Tables.

MEAN VALUE $X = (1/n) \sum X_i$ n=6

STANDARD DEVIATION $S.D. = \{(1/n) \sum (X_i - X)^2\}^{0.5}$

COEFFICIENT OF VARIATION $C.O.V. = S.D./X * 100\%$

X_i = An Individual Value

Table-4.1 (A) Variation of the Density of Concrete Made With No.1 Sawdust For Curing Age of 7 Days as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	Density (Kg/m^3) X	S.D.	C.O.V. %
1.0	436.02	3.5	0.87
2.0	555.00	3.5	0.62
3.0	684.01	5.1	0.73
4.0	740.00	4.3	0.56
5.0	837 10	2.4	0.29
6.0	920.00	3.2	0.35
7.0	1025.02	3.9	0.38
8.0	1078.00	4.5	0.41
9.0	1116.00	5.3	0.48
10.	1171.10	5.5	0.47
11.0	1204.20	8.0	0.38
12.0	1278.10	8.2	0.31
13.0	1308.12	6.5	0.32

Table-4.1 (B) Variation of the Density of Concrete Made With No.1 Sawdust For Curing Age of 28 Days as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	Density (Kg/m^3) $\bar{X}$	S.D.	C.O.V. %
1.0	454.30	3.0	0.66
2.0	560.00	2.9	0.51
3.0	700.00	2.6	0.37
4.0	771.12	3.6	0.47
5.0	862.60	4.0	0.46
6.0	970.00	3.8	0.40
7.0	1048.00	2.6	0.25
8.0	1100.00	4.2	0.38
9.0	1130.90	4.8	0.43
10.0	1176.00	2.9	0.25
11.0	1214.00	3.6	0.30
12.0	1283.00	4.2	0.37
13.0	1332.01	5.1	0.38

Table-4.1 (C) Variation of the Density of Concrete Made With No.2 Sawdust For Curing Age of 7 Days as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	Density (Kg/m^3) X	S.D.	C.O.V. %
2.0	589.00	3.5	0.61
3.0	740.00	3.2	0.45
4.0	842.50	4.2	0.50
5.0	953.38	4.8	0.50
6.0	1101.50	3.9	0.35
7.0	1125.44	4.1	0.36
8.0	1242.44	5.0	0.40
9.0	1289.10	3.6	0.28
10.0	1365.10	4.9	0.36
11.0	1399.29	5.2	0.37
12.0	1423.31	5.0	0.35
13.0	1476.00	4.2	0.28

Table-4.1 (D) Variation of the Density of Concrete Made With No.2 Sawdust For Curing Age of 28 Days as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	Density (Kg/m^3) X	S.D.	C.O.V. %
2.0	595.00	3.2	0.55
3.0	752.00	3.8	0.52
4.0	850.90	4.6	0.54
5.0	978.08	4.2	0.43
6.0	1111.00	5.0	0.45
7.0	1158.52	3.9	0.31
8.0	1266.37	4.8	0.38
9.0	1313.68	5.2	0.40
10.0	1381.87	5.6	0.41
11.0	1413.01	4.3	0.30
12.0	1437.00	4.0	0.28
13.0	1480.00	4.5	0.30

Table-4.2.1 (A) Variation of the Water Absorption of the Concrete Made With No.1 Sawdust Soaking in Water for 1 Hour as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X_{1h} %	S.D.	C.O.V. %
1.0	128.20	0.21	0.16
2.0	70.00	0.31	0.43
3.0	46.63	0.19	0.41
4.0	36.60	0.11	0.30
5.0	30.30	0.20	0.66
6.0	26.60	0.12	0.45
7.0	24.53	0.09	0.37
8.0	22.80	0.12	0.53
9.0	20.50	0.10	0.49
10.0	19.08	0.08	0.42
11.0	17.80	0.10	0.57
12.0	17.00	0.09	0.54
13.0	16.5	0.11	0.67

Table-4.2.1 (B) Variation of the Water Absorption of the Concrete Made With No.1 Sawdust Soaking in Water for 24 Hours as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X_{24h} %	S.D.	C.O.V. %
1.0	135.45	0.20	0.15
2.0	94.40	0.11	0.13
3.0	63.16	0.08	0.13
4.0	50.60	0.10	0.20
5.0	43.19	0.09	0.21
6.0	37.03	0.09	0.24
7.0	35.50	0.07	0.20
8.0	33.80	0.11	0.33
9.0	29.90	0.08	0.27
10.00	28.37	0.07	0.25
11.00	26.51	0.09	0.33
12.0	25.20	0.10	0.37
13.0	24.40	0.09	0.37

Table-4.2.1 (C) Variation of the Water Absorption of the Concrete Made With No.1 Sawdust Soaking in Water for 48 Hours as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X_{48h} %	S.D.	C.O.V. %
1.0	136.48	0.21	0.15
2.0	95.50	0.17	0.19
3.0	63.90	0.12	0.19
4.0	50.90	0.11	0.22
5.0	43.90	0.10	0.23
6.0	37.50	0.09	0.24
7.0	35.90	0.09	0.25
8.0	34.10	0.08	0.23
9.0	30.20	0.10	0.33
10.0	28.63	0.09	0.31
11.0	26.70	0.11	0.40
12.0	25.50	0.08	0.29
13.0	24.70	0.08	0.32

Table-4.2.1 (D) Variation of the Water Absorption of the Concrete Made With No.2 Sawdust Soaking in Water for 1 Hour as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X_{1h} %	S.D.	C.O.V. %
2.0	49.53	0.23	0.46
3.0	30.09	0.18	0.59
4.0	23.63	0 10	0.42
5.0	20.63	0.12	0.59
6.0	17.83	0.08	0.50
7.0	16.62	0.14	0.90
8.0	15.60	0.03	0.21
9.0	14.40	0.07	0.50
10.0	13.35	0.10	0.85
11.0	12.50	0.12	1.07
12.0	11.89	0.09	0.80
13.0	11.40	0.14	1.30

Table-4.2.1 (E) Variation of the Water Absorption of the Concrete Made With No.2 Sawdust Soaking in Water for 24 Hours as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X_{24h} %	S.D.	C.O.V. %
2.0	72.00	0.100	0.14
3.0	45.25	0.090	0.19
4.0	35.47	0.060	0.17
5.0	30.80	0.090	0.29
6.0	26.65	0.110	0.41
7.0	25.50	0.100	0.38
8.0	23.63	0.080	0.31
9.0	21.20	0.097	0.41
10.0	19.87	0.110	0.48
11.0	18.40	0.089	0.40
12.0	17.89	0.095	0.45
13.0	17.23	0.068	0.32

Table-4.2.1 (F) Variation of the Water Absorption of the Concrete Made With No.2 Sawdust Soaking in Water for 48 Hours as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X_{48h} %	S.D.	C.O.V. %
2.0	73.73	0.190	0.25
3.0	46.10	0.120	0.25
4.0	36.00	0.085	0.26
5.0	31.30	0.095	0.29
6.0	26.92	0.100	0.35
7.0	25.74	0.120	0.42
8.0	23.87	0.079	0.31
9.0	21.50	0.097	0.38
10.0	20.18	0.063	0.27
11.0	18.75	0.088	0.38
12.0	18.08	0.074	0.34
13.0	17.44	0.098	0.46

Table-4.3 (A) Variation of the Boiling Water Absorption of the Concrete Made With No.1 Sawdust as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X %	S.D.	C.O.V. %
2.0	120.49	0.12	0.13
3.0	85.55	0.19	0.32
4.0	69.29	0.23	0.50
5.0	60.02	0.18	0.45
6.0	50.01	0.08	0.24
7.0	46.94	0.24	0.73
8.0	40.41	0.24	0.80
9.0	36.48	0.20	0.71
10.0	32.29	0.12	0.46
11.0	30.78	0.82	0.33
12.0	28.92	0.10	0.41
13.0	27.32	0.28	1.20

Table-4.3 (B) Variation of the Boiling Water Absorption of the Concrete Made With No.2 Sawdust as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	X	S.D.	C.O.V. %
2.0	90.01	0.120	0.13
3.0	59.74	0.190	0.32
4.0	46.39	0.230	0.50
5.0	40.07	0.180	0.45
6.0	33.35	0.080	0.24
7.0	31.90	0.240	0.73
8.0	29.85	0.240	0.80
9.0	27.03	0.200	0.71
10.0	25.20	0.120	0.46
11.0	23.50	0.082	0.33
12.0	22.70	0.100	0.41
13.0	21.92	0.280	1.20

Table-4.4 (A) Variation of the Drying Shrinkage of the Concrete Made With No.1 Sawdust As a Function of Cement/Sawdust and a Function of the Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	D.S X	S.D.	C.O.V. %
3.0	700.00	0.524	0.004	0.89
5.0	862.60	0.360	0.005	0.93
7.0	1048.0	0.274	0.003	0.87
9.0	1130.9	0.165	0.002	0.69
11.0	1214.0	0.134	0.001	0.60
13.0	1332.0	0.102	0.002	0.80

D.S. = Drying Shrinkage

Table-4.4 (B) Variation of the Drying Shrinkage of the Concrete Made With No.2 Sawdust As a Function of Cement/Sawdust and a Function of the Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	D.S. X	S.D.	C.O.V. %
2.0	595.00	0.501	0.003	0.60
4.0	850.00	0.304	0.004	1.30
6.0	1111.00	0.161	0.001	0.62
8.0	1266.40	0.114	0.001	0.87
10.0	1381.80	0.108	0.001	0.93
12.0	1437.0	0.102	0.008	0.78

D.S. = Drying Shrinkage

Table-4.5.1 Variation of the Thermal Conductivity of the Concrete Made With No.1 sawdust as a Function of Cement/sawdust Ratio Based on Same Mean Temperature (T_m = 25 °C) and Same Temperature Different (ΔT = 14 °C).

Cement/Sawdust	Density (Kg/m^3)	K_m (W/m°C)	R_m (W/°C)
2.0	560.0	0.13	0.170
3.0	700.0	0.17	0.145
4.0	771.0	0.19	0.134
5.0	862.0	0.22	0.114
6.0	970.0	0.26	0.096
7.0	1048.0	0.30	0.084
8.0	1100.5	0.318	0.078
9.0	1130.91	0.324	0.076
10.0	1176.0	0.327	0.075
12.0	1283.0	0.40	0.066

Table-4.5.2 Variation of the Thermal Conductivity of the Concrete Made With No.1 sawdust as a Function of Different Mean Temperature (T_m) Based on Same Bulk Density of the Concrete (862.0 Kg/m^3).

T_m (°C)	ΔT (°C)	K_m (W/m°C)	R_m (W/°C)
15.0	14.0	0.218	0.114
25.0	14.0	0.224	0.112
35.0	14.0	0.227	0.110
45.0	14.0	0.229	0.109

Table-4.6.1 (A) Variation of the Compressive Strength of the Concrete Made With No.1 Sawdust After Freezing-Thawing Cycling Test as a Function of Cement/Sawdust Ratio.

Cement/sawdust	C.S. (MPa) X	S.D.	C.O.V. %
1.0	1.05	0.010	0.80
2.0	1.70	0.020	0.93
3.0	4.09	0 040	0.97
4.0	5.33	0.076	1.43
5.0	8.28	0.100	1.20
6.0	11.28	0.110	0.97
7.0	13.35	0.088	0.66
8.0	15.65	0.080	0.51
9.0	17.57	0.190	1.10
10.0	19.63	0.200	1.00
11.0	21.29	0.110	0.52
12.0	23.20	0.080	0.34
13.0	29.28	0.120	0.40

C.S. = Compressive Strength

Table-4.6.1 (B) Variation of the Compressive Strength of the Concrete Made With No.1 Sawdust Without Freezing-Thawing Cycling Test as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	C.S. (MPa) X	S.D.	C.O.V. %
1.0	1.03	0.009	0.80
2.0	1.80	0.010	0.44
3.0	4.21	0.030	0.71
4.0	5.43	0.030	0.55
5.0	8.53	0.080	0.93
6.0	11.72	0.070	0.59
7.0	13.62	0.070	0.51
8.0	15.80	0.085	0.54
9.0	18.11	0.090	0.45
10.0	20.03	0.140	0.69
11.0	22.18	0.100	0.45
12.0	23.67	0.220	0.92
13.0	29.58	0.210	0.68

C.S. = Compressive Strength

Table-4.6.1 (C) Variation of the Compressive Strength of the Concrete Made With No.2 Sawdust After Freezing-Thawing Cycling Test as a Function of Cement/Sawdust Ratio.

Cement/Sawdust	C.S. (MPa) X	S.D.	C.O.V. %
2.0	2.18	0.030	1.30
3.0	4.35	0.020	0.46
4.0	6.88	0.050	0.61
5.0	10.19	0.058	0.57
6.0	14.52	0.120	0.77
7.0	16.44	0.140	0.85
8.0	19.24	0.220	1.00
9.0	22.86	0.180	0.75
10.0	25.86	0.200	0.69
11.0	29.10	0.120	0.39
12.0	31.14	0.100	0.30
13.0	33.89	0.072	0.20

C.S. = Compressive Strength

Table-4.6.1 (D) Variation of the Compressive Strength of the Concrete Made With No.2 Sawdust Without Freezing-Thawing Cycling Test as a Function of Cement/Sawdust Ratio.

Cement/sawdust	C.S. (MPa) X	S.D.	C.O.V. %
2.0	2.28	0.02	0.84
3.0	4.57	0.04	0.87
4.0	7.10	0.09	1.00
5.0	10.61	0.11	1.01
6.0	15.00	0.10	0.62
7.0	16.60	0.08	0.48
8.0	20.08	0.22	1.00
9.0	23.30	0.21	0.85
10.0	26.44	0.11	0.37
11.0	30.08	0.09	0.28
12.0	31.40	0.19	0.57
13.0	34.50	0.23	0.65

C.S. = Compressive Strength

Table-4.7 (A) Variation of the Compressive Strength of the Concrete Made With No.1 Sawdust for Curing Age of 7 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	C.S. (MPa) X	S.D.	C.O.V. %
1.0	436.02	0.08	0.002	2.0
2.0	555.00	1.18	0.01	0.82
3.0	684.00	2.88	0.01	0.35
4.0	740.00	4.12	0.02	0.48
5.0	837.10	5.50	0.05	0.99
6.0	920.00	7.51	0.05	0.60
7.0	1025.02	9.01	0.03	0.33
8.0	1078.00	10.80	0.06	0.56
9.0	1116.00	12.21	0.09	0.74
10.0	1171.10	13.70	0.13	0.94
11.0	1204.20	16.40	0.12	0.73
12.0	1278.10	18.60	0.17	0.91
13.0	1308.12	20.80	0.25	1.20

C.S. = Compressive Strength

Table-4.7 (B) Variation of the Compressive Strength of the Concrete Made With No.1 Sawdust for Curing Age of 28 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	C.S. (MPa) X	S.D.	C.O.V. %
1.0	454.3	0.8	0.012	1.50
2.0	560.00	1.73	0.010	0.49
3.0	700.00	3.82	0.018	0.47
4.0	771.12	5.21	0.040	0.77
5.0	862.60	8.21	0.060	0.77
6.0	970.00	11.21	0.100	0.89
7.0	1048.00	13.30	0.070	0.53
8.0	1100.50	15.54	0.080	0.51
9.0	1130.90	17.51	0.140	0.80
10.0	1176.00	19.50	0.180	0.92
11.0	1214.00	22.00	0.200	0.95
12.0	1283.00	24.00	0.100	0.43
13.0	1332.00	28.01	0.190	0.65

C.S = Compressive Strength

Table-4.7 (C) Variation of the Compressive Strength of the Concrete Made With No.2 Sawdust for Curing Age of 7 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	C.S. (MPa) X	S.D.	C.O.V. %
2.0	589.00	1.41	0.012	0.85
3.0	740.00	2.81	0.04	1.40
4.0	842.50	5.12	0.08	1.50
5.0	933.38	7.28	0.12	1.60
6.0	1101.50	10.00	0.07	0.60
7.0	1125.44	11.50	0.12	0.91
8.0	1242.44	14.00	0.08	0.49
9.0	1289.10	17.10	0.15	0.78
10.0	1365.10	20.00	0.12	0.53
11.0	1399.29	22.80	0.09	0.37
12.0	1423.31	24.50	0.18	0.80
13.0	1476.00	27.00	0.24	0.82

C.S = Compressive Strength

Table-4.7 (D) Variation of the Compressive Strength of the Concrete Made With No.2 Sawdust for Curing Age of 28 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	C.S. (MPa) X	S.D.	C.O.V. %
2.0	595.00	2.08	0.014	0.67
3.0	752.00	4.50	0.02	0.51
4.0	850.90	6.50	0.04	0.56
5.0	978.08	10.51	0.06	0.63
6.0	1111.00	14.50	0.07	0.47
7.0	1158.52	16.21	0.15	0.94
8.0	1266.37	19.72	0.13	0.66
9.0	1313.68	22.80	0.18	0.78
10.0	1381.87	26.01	0.21	0.74
11.0	1413.00	29.02	0.08	0.26
12.0	1437.00	31.00	0.11	0.34
13.0	1480.00	35.00	0.23	0.67

C.S = Compressive Strength

Table-4.8 (A) Variation of the Bending Strength of the Concrete Made With No.1 Sawdust for Curing Age of 7 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	B.S. (MPa) $\bar{X}$	S.D.	C.O.V. %
1.0	436.02	0.04	0.004	8.40
2.0	555.0	0.54	0.012	2.10
3.0	684.00	1.12	0.020	1.78
4.0	740.00	1.55	0.016	1.21
5.0	837.10	2.18	0.040	1.90
6.0	920.00	2.30	0.020	0.69
7.0	1025.02	2.68	0.030	1.04
8.0	1078.00	2.80	0.020	0.63
9.0	1116.00	3.00	0.015	0.46
10.0	1171.10	3.15	0.020	0.60
11.0	1204.20	3.28	0.022	0.64
12.0	1278.10	3.40	0.030	0.82
13.0	1308.12	3.61	0.018	0.45

B.C. = Bending Strength

Table-4.8 (B) Variation of the Bending Strength of the Concrete Made With No.1 Sawdust for Curing Age of 28 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	B.S. (MPa) X	S.D.	C.O.V. %
1.0	454.30	0.06	0.0032	5.0
2.0	560.00	0.58	0.018	3.0
3.0	700.00	1.21	0.011	0.91
4.0	771.12	1.81	0.019	1.00
5.0	862.60	2.30	0.020	0.86
6.0	970.00	2.70	0.018	0.57
7.0	1048.00	3.05	0.013	0.40
8.0	1100.50	3.18	0.012	0.37
9.0	1130.90	3.30	0.018	0.59
10.0	1176.00	3.41	0.020	0.58
11.0	1214.00	3.58	0.018	0.50
12.0	1283.00	3.72	0.020	0.52
13.0	1332.00	3.86	0.024	0.66

B.C. = Bending Strength

Table-4.8 (C) Variation of the Bending Strength of the Concrete Made With No.2 Sawdust for Curing Age of 7 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	B.S. (MPa) X	S.D.	C.O.V. %
2.0	589.0	0.65	0.016	2.2
3.0	740.0	1.38	0.016	1.2
4.0	842.5	2.1	0.018	0.81
5.0	933.38	2.7	0.02	0.64
6.0	1101.5	3.2	0.018	0.54
7.0	1125.44	3.36	0.018	0.64
8.0	1242.44	3.6	0.02	0.56
9.0	1289.10	3.8	0.02	0.56
10.0	1365.10	4.01	0.019	0.47
11.0	1399.29	4.28	0.02	0.47
12.0	1423.31	4.34	0.018	0.42
13.0	1476.00	4.46	0.02	0.45

B.C. = Bending Strength

Table-4.8 (D) Variation of the Bending Strength of the Concrete Made With No.2 Sawdust for Curing Age of 28 Days as a Function of Cement/Sawdust Ratio and a Function of Density of the Concrete.

Cement/Sawdust	Density Kg/m^3	B.S. (MPa) X	S.D.	C.O.V. %
2.0	595.0	0.70	0.01	1.2
3.0	752.00	1.50	0.014	1.00
4.0	850.90	2.30	0.020	0.86
5.0	978.08	2.98	0.016	0.50
6.0	1111.00	3.50	0.020	0.58
7.0	1158.52	3.72	0.021	0.58
8.0	1266.37	4.10	0.026	0.66
9.0	1313.68	4.23	0.023	0.56
10.0	1381.87	4.48	0.025	0.56
11.0	1413.00	4.60	0.028	0.60
12.0	1437.00	4.65	0.027	0.57
13.0	1480.00	4.72	0.030	0.62

B.C. = Bending Strength