Green plants' extracts' potential as concrete admixtures

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DECLARATION

This thesis is the original work and has not been presented for a degree in any other University.

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DEDICATION

This work is dedicated to my parents, Theresia Njoki Chege, and Johana Chege Kiarie for their role as great parents. I deeply appreciate their unconditional love, devotion to the welfare of others, and foresight.

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ABBREVIATIONS

ACV: Aggregates Crushing Value

ASTM: American Society of Testing and Materials

BRE: Building Research Establishment (Second Edition)

BS: British Standards

CP: Code of practice

CSEB: Compressed stabilized earth blocks

CSEB: Compressed stabilized earth blocks

DOE: Department of environment

FM: Fineness modulus

ha: Hectare

JKUAT: Jomo Kenyatta University of Agriculture and Technology

KFS: Kenya Forest Service

kg: kilogramme

KNBS: Kenya National Bureau of Statistics

LSF: Lime saturation factor

OPC: Ordinary Portland cement

SSD: Saturated surface dry

UN: United Nations

WC: Water closet

ACRONYMS

C_2S: Dicalcium silicate

C_3A: Tricalcium aluminate

C_3S: Tricalcium silicate

C_3S: Tricalcium silicate

C_4AF: Tetracalcium aluminoferrite

CO_2: Carbon dioxide

C-S-H: Calcium silicate hydrate

d: Concrete cylinder diameter (mm)

F: Maximum applied force (N)

f: Beam strength in flexure (N/mm^2)

f_c: The specified characteristic strength (N/mm^2)

f_m: The target mean strength (N/mm^2)

f_t: Cylinder splitting tensile strength (N/mm^2)

k: Constant

l: Concrete cylinder length (mm)

M: Bending moment (N.mm)

NaLS: Sodium Lignin Sulphonate

Q_H: Heat of cement hydration (J/g)

s: Standard deviation

w/c: Free - water/cement ratio

W_c: Free water required when coarse aggregates are used

W_f: Free water required when fine aggregates are used

Z: Section modulus (mm^3)

ABSTRACT

In Kenya, the rate of construction of building structures for homes falls short of what is required to meet the demand. High cost of buildings is a major contributing factor to this unfortunate condition. Cost of building materials significantly influences the overall cost of the structure. Today, concrete is the most widely used construction material and most modern buildings would have some structural elements made of concrete.

This research investigated the feasibility of developing a concrete admixture from green plants biomass of a locally growing plant that could be cheaper than the available alternative. In the years 2010/2011, Kenya had over 90,000 hectares of industrial forest plantations composed of mainly Cypress, Pines and Eucalyptus (Kenya Forest Service 2012). These plants were selected for study on account of their guaranteed availability. Waste products are the bark and saw dust during conversion process, at saw mills and shavings in the wood products workshops. These wastes can be the raw materials for concrete admixtures.

For each plant, both the bark and wood were subjected to extraction process. The extraction was effected by the use of tap water, heat (121^{o}C), and pressure (0.1 N/mm^{2}). The liquor so obtained, without further processing, was used as a concrete admixture at varying dosage levels. These dosages were expressed as mass percentages of the cement content. The dosages were incrementally varied from 0.0% (control) to 47.5% for the bark extract. For the wood extracts, the dosages were 10%, 20% and 40%. For each concrete mix, the mass of the mixing water was reduced by a mass equal to the mass of the dosage of the plant extract. At the upper dosage limit of 47.5%, the mixing water had been completely substituted with the plant extract, taking into account the water absorption of the aggregates.

The strength tests were carried out at 3, 7, 28, and 61 days. The casting of concrete for strength tests was done at a constant workability of 45 mm slump; with a tolerance of 5 mm. Use of the admixtures resulted in compressive strength improvement of 10%, 17%, and 10% for cypress, pine and eucalyptus, respectively. Hence, from strength

consideration, pine extract was found to be the most effective. Estimated saving in cement content, when pine extract was used, was 9.84%. Cement accounts for 70% of the concrete materials cost. Therefore, concrete materials cost saving was about 7%.

Mixes for workability testing were done at a constant water/cement ratio of 0.61. Slump test was used for the assessment of the workability. Workability improved from 45mm (control) to 155mm, 160 mm, and 165 mm slump for cypress, pine and eucalyptus, respectively. Therefore, from workability assessment, eucalyptus extract, was the most effective.

CHAPTER ONE

INTRODUCTION

1.1 Background

In many parts of the world, the current civilization is in need of more infrastructural development for purposes that might include housing people. Design and development of housing for human habitation should be understood in the wider context that embraces not only the house fabric but also well planned environment, provision of basic necessities such as potable water, sanitation, electricity, roads and telecommunication networks. Availability of the house structure and all the said necessary services is what may be said to constitute adequate human housing.

Human settlements, throughout history, have always developed around areas of economic activities, such as industrial manufacturing, transportation and agriculture. Economic activities require infrastructure in the form of workshop houses, warehouses, office space, roads and bridges, among others. In order to provide welfare services, such as health, education and sports facilities, in a particular community, building structures are prerequisites.

The United Nations Universal Declaration of Human Rights of 10 December, 1948, under Article 25, recognizes adequate housing to every citizen as a human right. This has been further reaffirmed by other international instruments such as International Convention on Economic, Social and Cultural Rights of 16 December, 1966 (ratified by Kenya on 01 May, 1972) (UN General Assembly, 1966) and the Istanbul Declaration and Habitat Agenda of June, 1996 (UN-HABITAT, 1996).

Globally, a total of 924 million people, in the year 2001, which was then about 32 per cent of the world's total urban population, lived in informal settlements (slums) (UN–HABITAT, 2003). The same report predicts that this figure is likely to double by the year 2030, if no deliberate mitigating intervention measures are put in place by the relevant governments. Kenya has been a UN member State since 16 December, 1963.

1.1.1 Housing situation in Kenya

Out of their own conviction, and encouraged by the good intentions of the above stated international coventions, Kenyan society and its relevant institutions such as State and Governments have constantly made practical efforts to make housing available to citizens. The first comprehensive Housing Policy for Kenya was developed in 1966/67 as Sessional Paper No.5. The annual housing requirements then were 7,600 and 38,000 new units in urban and rural areas respectively. The policy advised the government to provide the maximum number of people with housing at the lowest possible cost. It also advocated for slum clearance and mobilization of resources for housing development through aided self - help (site and service schemes) and co-operative efforts. Other areas addressed in the policy paper included increased research in locally available building materials and construction techniques, and housing of civil servants through home ownership schemes in urban areas as well as institutional and pool housing schemes in remote stations**.** In spite of this very early effort, in independent Kenya, to address housing problems, demand for adequate housing has continued to outstrip the supply, particularly in urban areas for a variety of reasons (Republic of Kenya: Ministry of Lands and Housing, 2004).

1.1.2 Factors affecting housing development industry

Issues adversely affecting availability of homes in Kenya include, poor national economic performance; resulting in high level of poverty, population dynamics (rapid expansion, and fast pace of urbanization), land scarcity (especially in the urban areas), rigid construction industry regulatory system, high cost of building materials and inadequate and costly house financing. These factors have effects of varied magnitude on housing depending on location: urban or rural areas. In the urban areas, land, finance, and regulatory system are the main hindrances while in the rural setting, financing and building materials are the key problems (Mutunga, 2004).

Monitoring of Kenya's population changes began in the Nineteenth century with the first recorded census having been held in the year 1897. Since then, up to the last census of the year 2009, a period of 112years, the population has consistently grown exponentially as graphically illustrated in Fig. 1.1 (Republic of Kenya: Ministry of State for Planning National Development and Vision 2030; KNBS, 2010).

By 1966/67, three years after independence of 12 December, 1963, annual population growth rate had reached 3 % (Republic of Kenya: Ministry of Lands and Housing, 2004).

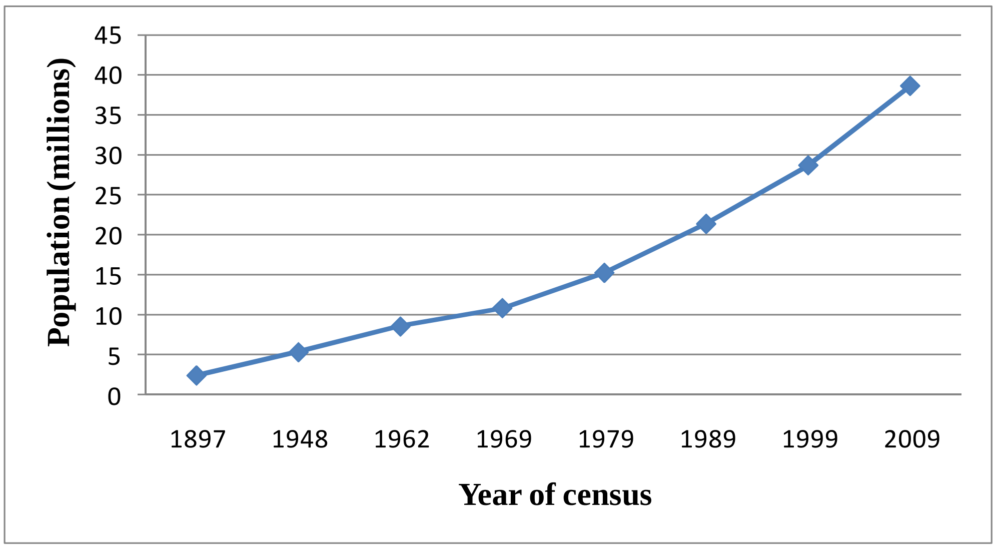


Figure 1.1: Kenya population and housing census results

Housing development has not been able to match that fast growth of population.

Rapid rural to urban areas migration, of mainly young people, in search of employment and business opportunities has raised this housing problem to crisis proportions, in the concerned urban areas, resulting in what is variously referred to as urban human informal settlements or slums. By 1966/67 the urban annual population growth rate had attained a phenomenal figure of 5 to 6 per cent (Republic of Kenya: Ministry of Lands and Housing, 2004**)**. However, in absence of any institutionalized societal financial help, for people in dire financial circumstances, informal settlements remain the only choice such people have for a home. Many new migrants into urban setting fall into this economic bracket. On the positive side, most slum dwellers are people struggling to make an honest living, inside and outside the slums, within the context of extensive urban poverty and formal unemployment. Slums are also places in which the vibrant mixing of different cultures frequently results in new forms of artistic expression. Out of unhealthy, crowded and often dangerous environments can emerge levels of solidarity unknown in the suburbs of the rich. Against all odds, slum dwellers have developed economically rational and innovative shelter solutions for themselves. However, these few positive attributes do not in any way justify the continued existence of slums and should not be an excuse for the slow progress towards the goal of adequate shelter for all.

The Republic of Kenya has an area of approximately 582,646 sq. km. comprising of 97.8 % land and 2.2 % water surface. In agricultural terms, the land area (97.8 % of the total geographical territory) falls into three broad zones: high, medium and low potential areas. The high and medium areas, put together, add up to about 20 % of the land area (113,966 km^2) while the low potential areas (arid and semi - arid areas) cover the rest 80 % (455,862 km^2). Forests, woodlands, national reserves and game parks cover 10 % of the total surface area (58264 km^2). (Republic of Kenya: Ministry of Lands 2009**)**. Economic activities such as intensive agriculture, livestock husbandry, manufacturing and services' industry have evolved in the 20 % fraction of the area of the land. Consequently, it is here that most of the urban centres and rural settlements are to be found. While this small fraction of the total land surface remains constant, demand for it increases with increasing population resulting in very high land prices. Land tenure refers to the terms and conditions under which rights to land and land – based resources are acquired, retained, used, disposed off or transmitted. The categories of tenure operative in Kenya are private (modern) ownership, communal (customary) ownership, and public (state) ownership.

Private ownership refers to land lawfully held, managed and used by an individual or other entity consequent to consolidation, adjudication and registration. By 1990, the land under private ownership comprised 6% of the 582,646 sq. km. This category of land is what is in the free market. The small size of the fraction of the total land area contributes to the high prices of building land.

Communal (customary) ownership refers to trust land (formerly native areas) vested in relevant county Governments awaiting small holder registration and will eventually, after consolidation, adjudication and registration, come under the private ownership. Administration of land in this category is in compliance with Trust Land Act (Cap 288). By 1990, land in this category comprised 64% of the land area. Although individual people may have rights to this land, such rights are not documented, as yet, and therefore the land cannot be used as collateral to secure credit for home development.

Public (state) ownership applies to land that was formerly referred to as Crown land. This includes forest land, National reserves and game parks, alienated and unalienated land. The relevant legislation is the Government Land Act (Cap 280). By 1990 this category of land comprised 20% of the total land area. Forests, national reserves and game parks accounted for 10% (58,264 km^2) (Kameri–Mbote, 2013).

The building construction industry, in Kenya, is effectively and comprehensively regulated. This is achieved through a set of regulations, specifications and recommendations that have been enacted into law: “The local government (adoptive by-laws) (building) order 1968; also referred to as “The Kenya building code”. However, since its introduction, some 45 years ago, no revision of the code has been done to make it reflect the reality of changed background in terms of the economy, demography, technology, and new concerns for a safe and healthy planet.

For construction of building walls, the only materials covered by the code are natural stone, burnt clay bricks, concrete blocks and sand lime blocks. However, there is now evidence that rammed earth can also be successfully used for monolithic wall construction (Fundi, Maritim, & Mutuku, 2011**)**, and compressed stabilized earth blocks (CSEB) for masonry wall construction. It should also be noted that natural stone is of finite quantum and sand, though being redeposited by nature, is probably being consumed at a rate, higher than it is being recreated. Engineers and experts in relevant sciences, therefore, need to research on new building materials that can be used sustainably. The Building Code ought to have an in – built flexibility that recognizes and adopts new technology as it emerges without undue delay in order to timely address the issue of depletion of naturally available building materials.

In the manufacture of concrete building blocks, cement is used. The mix used for concrete blocks is between 1: 6 and 1:8; cement: aggregates, respectively. Therefore cement content, by weight, for these blocks ranges between 14.3% and 11.1% (Murdock & Brook, 1979**)**. To produce one ton of cement, one ton of carbon dioxide is released into the atmosphere; contributing to global warming (Neville, 2011). Therefore, besides the sustainability and low cost of CSEB, their use will also contribute towards a safer planet.

Financial resources are important inputs in housing. The sources of funds are few; a situation that makes mortgages very expensive and qualifying terms very stringent. At the top of the housing market are households that can afford housing of good quality. In the middle category fall the middle – income group, which is mainly composed of salaried workers as well as the self – employed. This economic group is not well catered for in the provision of housing at the moment and end up in the housing meant for the low – income class. The third category, which forms the majority of households, is the low – income earners. These are the most affected by housing problems arising from insufficient housing and the displacement brought about by inadequate housing for the middle **–** income class.

Mortgage lending by banks and other financial institutions only benefit the high income groups, mainly in urban areas. The borrowing needs of other economic groups and rural areas remain insufficiently addressed. The commercial banks are restricted from investing in housing by the provisions in the banking Act [Laws of Kenya: Cap 488, Section 12(c)]. The Building Societies Act Section 22 (2) [Laws of Kenya (Cap 489)] restricts the resource mobilization capability of Building Societies to two thirds of their mortgage portfolio. Section 24 (1 and 2), of the same act, dictates the type of security that Building Societies may take to secure their lending. Section 24 (3) further restricts the amount that the Building Societies may lend to each individual borrower. The legislation should be revised to make it more enabling for house delivery.

Rent control is a tool that regulates rents and also provides a legal framework for landlord/tenant relationship. House development is a business like any other and people making these investments do so with the aim of getting profits. If they, investors, are subjected to rules that prevent them from achieving their objectives, then they will be discouraged from putting their resources in housing. Rent Restriction Act (Laws of Kenya: Cap 296) and the Landlords and Tenants Act (Laws of Kenya: Cap 301), in some sections, restrict the operations of the rental market in favour of the interests of the tenants more than those of the landlords and by so doing discourage investment in rental housing (Republic of Kenya: Ministry of Lands and Housing: Sessional Paper No.3: National housing policy for Kenya, 2004). This legal framework should be revised to make it more conducive to investment without compromising the interests of both tenants and landlords.

1.2 Statement of the problem

Shortage of building structures was cited in section 1.1.1, and the situation has not improved to date. During the 1974 – 1978 plan period, for example, 25,000 dwelling units were constructed compared with a demand of 50,000 units. The comparable supply and demand figures for the period 1997 - 2001 are 112,000 and 560,000, respectively. By the year 2004, the average annual urban areas housing demand was estimated at 150,000 units against a supply of 30,000 – 50,000 units. In addition, an estimated 300,000 dwelling units are required annually in the rural Kenya (Republic of

Kenya: Ministry of Lands and Housing: Sessional Paper No.3: National housing policy for Kenya, 2004**)**.

According to the Kenya population and housing census carried out in the year 1999, the population, then, stood at 28.7 million. Thirty-two percent (9.2 million) of these people lived in urban areas and the rest (19.5 million) in rural Kenya. The country-wide survey, in the census, revealed that only about 25% of the total population lived in shelters that had reasonable chances of qualifying as adequate homes; as may be inferred from Table 1.1.

Adequate shelter, among other benefits, provides protection against weather elements, security to life and property, privacy; as demanded by cultural values, convenience of living, ease of maintaining good human health and pleasant environmental aesthetics. The focus of this research is to address the shortage of housing by researching on a material that could lower the cost of concrete, as a construction material.

Table 1.1: The 1999 Kenya population and housing census results

	Type of house wall construction materials					Total dwelling units
	Stone	Brick/ block	Mud/ brick	Mud/ cement	Others	
Number of dwelling units (million)	1.1	1.6	5.1	0.7	2	10.4
Percentage of total	10.2	15	49.3	6.4	19.1	100
Combined percentage of the proper houses	25.2					

(Republic of Kenya: Ministry of Finance and planning: Central Bureau of Statistics, 2004)

1.3 Justification

Factors that include construction materials, influencing cost of buildings are discussed in section 1.1.2. Concrete is the most widely used building construction material. Table 1.2 provides a typical normal concrete mix design materials output and the current, materials only, cost of producing 1.0 m^3 of concrete, in the locality of JKUAT. The material prices obtained from the merchants were given in Appendix A. From Table 1.2, cement accounts for 70% of the concrete materials cost. Enhancing the performance of cement and therefore reducing the amount required to produce concrete of a particular grade, and particular workability level, is the therefore, the most effective way of lowering the cost of concrete in a building.

In conservative terms, the facilities required for an adequate house for a middle income family are three bedrooms, a lounge, kitchen, shower and a water closet (WC). The minimum floor area for these facilities is of the order of 75 m^2. Standard concrete floor thickness is 150 mm. The volume of concrete required for the floor slab, is then 11.25 m^3. For concrete grade 20, workability level 30-60 mm slump and using Portland cement class 42.5 mix, design output was given in Table 1.2. Materials only, cost is also given in the same table.

Table 1.2: Mix design summary and materials cost

Quantities	Cement (kg)	Water (kg)	Fine aggregates (kg)	Coarse aggregates (kg)		
				10 mm	20 mm	40 mm
Per m^3	400.0	242.2	668.9	400.8	801.2	-
Cost (KSh.)	9,200.00	242.20	1337.80	801.60	1602.40	-
Total cost (KSh.)	9,200.00	3983.90				
Percentage cost	70	30				
Cost(KSh) per m^3	13183.90					

Using the concrete specified, the cement cost for the floor structural element, was KSh.103, 800. Assuming 10% improvement in performance of cement, the cost reduction in the floor element alone would be of the order of KSh.10,350. Other elements that require concrete include founadation, beams and, often times, roofs.

1.4 Objectives

1.4.1 Main objective

The main objective is to assess the potential of green plants' extracts as admixtures in concrete.

1.4.2 Specific objectives

1. To determine the basic material properties relevant to concrete production.
2. To determine the effects of plant extracts admixtures on the workability of the fresh mix, and strength of hardened concrete.
3. To determine the effect of extraction method on the performance of plant extracts as concrete admixtures.

1.5 Research questions

1. Given the concrete materials and laboratory testing equipment available for this research, can concrete mixes be designed, and made?
2. Can green plants extracts be made, and incorporated as admixtures in concrete, and the effects of their presence, on workability, and strength be tested?
3. Would extracts from different parts of the same plant affect the properties of concrete differently?

1.6 Scope

While many plant species are to be found in Kenya, this research investigated only the three plants: Cypress, Pine and Eucalyptus. In production of concrete mixes, cement strength classes 42.5 and 32.5 are readily available in the Kenyan market. Only cement class 42.5 was used for this work. Data published regarding strength and workability should be deemed to apply only when those plants and cement have been used.

1.7 Limitations

In the plants' extraction process, the digester could not attain a temperature higher than 121^{o} C, and pressure higher than 0.10 N/mm^2. Higher digester temperatures and pressures would have resulted in a more effective extraction. After digesting the plant material, the black liquor, so obtained, was expected to mainly contain hemicellulose (complex sugar) and lignin. Equipment to determine the relative proportions of the two organic compounds was not available.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The stated objective of this study was to investigate the feasibility of developing a concrete admixture from local plants. In line with this objective, concrete production procedure and materials were reviewed. The concrete mix design method used was that adopted by British practice. The materials for making concrete covered under the review were aggregates, cement water and lignin based admixtures

2.2 Concrete

Depending on the performance requirements, concrete may be produced as plain concrete, reinforced concrete or pre-stressed concrete. It is made by mixing together, in the right proportions, cement, water, aggregates (coarse aggregates and fine aggregates), admixtures, and additives. A normal concrete mix would not contain an admixture or an additive. When either an admixture or an additive or both of these ingredients are incorporated it is termed as a special concrete mix.

2.2.1 The advantages of concrete as a building material

Concrete is economical in the long run as compared with steel. Except cement, normal concrete can be made from locally available coarse and fine aggregates. It has high compressive strength and corrosive and weathering effects on concrete are minimal. In practice and without using an admixture, a concrete mix to give a 28 days cube compressive strength of up to 50 N/mm^2 can be designed **(**Kong and Evans 1985)**.** Green concrete can easily be handled and moulded into any shape or size and the formwork materials can be reused a number of times; resulting in economy. When used in combination with steel reinforcement, concrete has unlimited structural applications. It is durable, fire resistant, and requires very little maintenance.

2.2.2 The disadvantages of concrete as a building material

Concrete has low tensile strength and hence cracks easily. For this reason concrete is reinforced with steel bars or steel meshes in the regions of a structural member where tension is expected to occur. Fresh concrete shrinks on drying (initial drying shrinkage), and hardened concrete is liable to moisture and temperature movements. Moisture movement of concrete is about 60% of its initial drying shrinkage (Kong and Evans, 1985)**.** Provision of movement joints has to be made to avoid development of cracks due to these physical dimensional changes. Under a sustained loading, concrete undergoes creep, resulting in the reduction of the pre-stress in the pre-stressed concrete construction. Creep of concrete accounts for 5% – 15% of the total pre-stress loss (Martin, Croxton and Purkiss, 1989).The lack of ductility, inherent in concrete as a material, is disadvantageous with respect to earthquake resistant structural design.

Concrete is not entirely impervious to moisture and contains soluble calcium hydroxide which may cause efflorescence. Tricalcium silicate (C_3S) and dicalcium silicate (C_2S), which together constitute 70% - 80% of the Portland cement, hydrate to produce the same products, namely calcium silicate hydrate ($C_3S_2H_3$) and calcium hydroxide [$Ca(OH)_2$]. This explains the presence of calcium hydroxide in concrete. Water permeating through concrete dissolves the calcium hydroxide and on exit, on the other face of the concrete member, the $Ca(OH)_2$ reacts with carbon dioxide, from the atmosphere, to give calcium carbonate. After evaporation, calcium carbonate is left as a white deposit on the surface of the concrete; referred to as efflorescence. The process may be represented by the chemical equation:

$$\text{Calcium hydroxide } Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \qquad (2.1)$$

Efflorescence is of importance only as far as it mars the appearance of concrete (Neville, 2011).

2.2.3 Concrete mixes

In British practice, mixes may be designed in accordance with the current Building Research Establishment (BRE) procedure. The problem of mix design consists of selecting the correct proportions of cement, coarse aggregates, fine aggregates, and water to produce concrete having the specified properties. Properties of concrete that may be specified include workability of the fresh mix, compressive strength of the hardened concrete at a specified age, and durability. Durability requirement is stated by specifying the minimum cement content and or the maximum free-water/cement ratio. Mix proportions are derived in an attempt to produce a concrete having the required workability and strength. A trial mix is then made and tested for compliance with the requirements. If necessary, adjustment to the proportions is made to produce the revised trial mix.

Because of variability of concrete strengths, the mix must be designed to have a higher mean strength (target mean strength) than the specified characteristic strength. Hence the equation

$$\text{Target mean strength } (f_m) = \text{Characteristic strength } (f_c) + \text{Strength margin } (M) \qquad (2.2)$$

In this method of mix design (BRE 1997), workability of the fresh mix may be measured by either slump test, or Vebe time test. The total water in a concrete mix consists of the water absorbed by the aggregate to bring it to an SSD condition, and the free – water available for the hydration of the cement and for the lubrication of particles in the concrete. In practice, aggregates are often wet and they contain both absorbed water and free surface water so that the water added at the mixer is less than the free – water required. The workability of concrete depends, to a large extent on its free – water content. Similarly, the strength of concrete is better related to the free – water cement ratio since on this basis the strength of the concrete does not depend on the absorption characteristics of the aggregates. The free-water/cement ratios referred to in BRE are, by mass, of free – water to cement in the mix.

Coarse aggregates are classified as either crushed or uncrushed and their particle nominal sizes as 40 mm, 20 mm, and 10 mm (BRE, 1997). Fine aggregate particles' percentage passing 0.600 mm standard sieve is also required and is to be determined by sieve analysis test (BRE, 1997). A durable concrete is one which gives a satisfactory performance during an adequate life in a given environment. This includes providing protection of the steel against corrosion, in reinforced and pre-stressed concrete. Any factor that increases the strength of concrete also increases its durability.

2.2.4 Concrete admixtures and additives

An admixture is a material, other than the coarse aggregates, fine aggregates, cement or water added in small quantities during the mixing of concrete or mortar to produce some desired modification in one or more of concrete's properties (Neville, 2011). An additive is a material, other than the usual ingredients of cement, added during the manufacture of cement. It is used for the same purpose as an admixture (Jones, 1982).

Admixtures that allow a reduction in free water content for a concrete mix, for a given workability, or give a higher workability at the same free water content, are termed as plasticizers or water reducers (Schultz, 1980). The plasticizers may be used in all types of concretes including reinforced concrete, pre-stressed concrete, and plain concrete. These admixtures are especially required to produce flowing concrete. Other situations that demand high workability concrete include heavily reinforced deep beams, thin walls of water retaining structures with a high percentage of steel reinforcement, column and beam junctions, pumping concrete, and situations where cement content or heat of hydration need to be reduced (Shetty, 2009). Water reduction ranges from 5% to 15%; the actual level depending on the dosage. For concrete of a given workability, water reduction reduces the free-water/cement ratio for given cement content, or permit a reduction in cement content while maintaining the same free-water/cement ratio (Schutz, 1980).

At a constant workability, a plasticizer reduces the water requirements and therefore increases strength, due to the modification of the free-water/cement ratio. This increase in strength is greater than that indicated by water reduction alone. At the same cement content, a strength increase of 25% is typical. Increases in flexural strengths of concretes containing plasticizers are attained but they are not proportionally, as great as the increases in the compressive strength. Plasticizers increase strength at all ages. The very low free-water/cement ratios obtainable with the use of plasticizers result in high early strengths (Schultz, 1980).

The use of plasticizers has no effect on the heat of hydration of a given concrete. The total heat of hydration of concrete is reduced by taking advantage of the cement reductions made possible by the use of the plasticizers. Heat reduction is directly proportional to the cement reduction. Since plasticizers increase strength, significantly, it is possible to produce a particular grade of concrete at reduced cement content. The cost of cement so saved exceeds the cost of the admixture, resulting in more economic concrete (Schultz, 1980). Typical dosages of lignin based plasticizers are in the range 0.1% - 0.4%, by weight, of cement (Shetty, 2009).

The action of a plasticizer is to fluidify the mix and hence improve the workability of concrete, mortar or grout. Fineness of cement is of the order of 350 m^2 / kg. In this state of fine division, cement flocculates in wet concrete. The flocculation entraps certain amount of free water used in the mix and therefore all the water is not freely available to fluidify the mix. Plasticizers contain negatively charged particles which get adsorbed onto the cement particles, upon mixing the two; plasticizer and cement. The adsorption, therefore, creates particle-to-particle repulsive forces. The result is that cement particles are dispersed. After dispersion, the entrapped water is released and becomes available to lubricate the mix; resulting in higher workability.

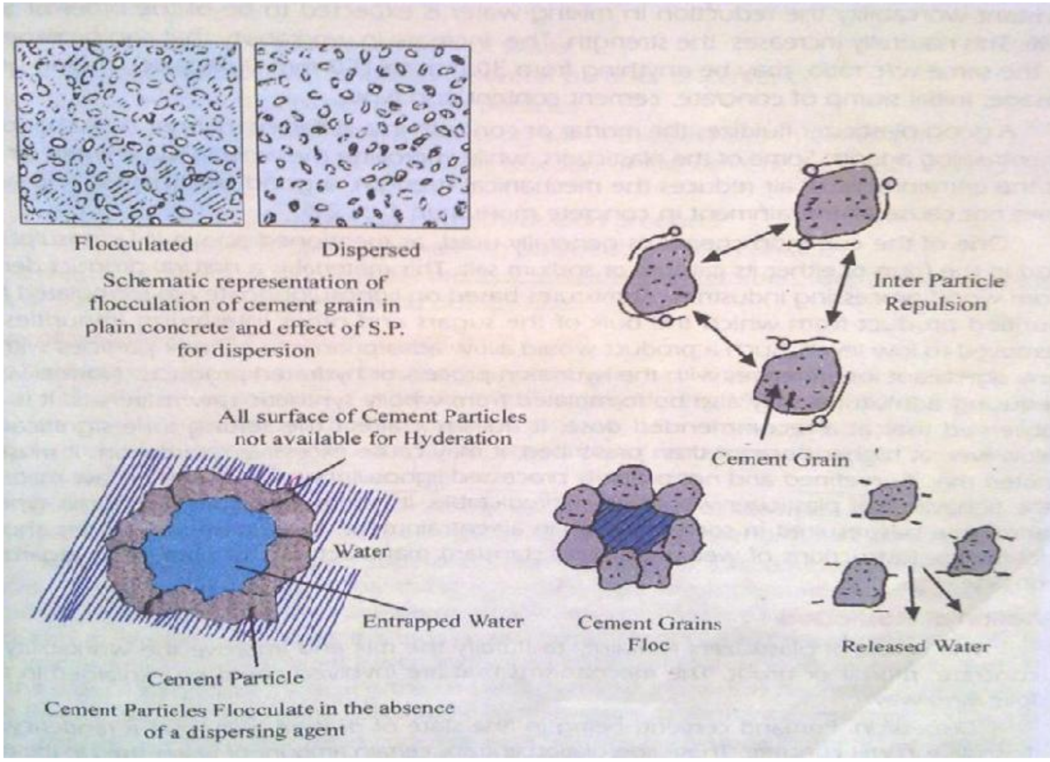


Figure 2.1: Effect of surface – active agents on dispersion of cement grains

In flocculated state, a cement particle has part of its surface in contact with adjoining particles. The areas of contact are not available for early hydration. After dispersion, the particle surface area, available for hydration increases; leading to higher rate of strength development. A more uniform distribution of the dispersed cement particles, throughout the concrete, reduces pockets of low cement particles concentration resulting in higher values of the average ultimate strength.

The chemical nature and physical structure of the hydration products are not affected by plasticizers. Fig. 2.1 is an illustration of some of these concepts (Shetty, 2009).

The common plasticizers include lignosulphonates. A lignosulphonate may be sodium lignin sulphonate, calcium lignin sulphonate, magnesium lignin sulphonate, or ammonium lignin sulphonate. These are compounds synthesized from lignin, which is an organic chemical extracted from plants.

2.2.5 Chemical and physical properties of plant extracts

The extracts used in this study contained the material that plants are made of. Trees are classified as either softwoods or hardwoods. The plant biomass can be separated into two categories of molecules: macromolecules and low molecular weight substances (Kare, 2004).

(a) Macromolecular substances:
- (i) Cellulose
- (ii) Hemicelluloses
- (iii) Lignin

The properties of lignin and hemicelluloses differ in softwood and hardwood. Properties of cellulose are the same in both woods.

(b) Low molecular weight substances:
- (i) Extractives (examples include terpenes, alcohols, aliphatic acids, and aromatic compounds)
- (ii) Mineral elements (examples include Potassium, Calcium, Magnesium and Silicon)

An illustration of the wood composition matrix is presented in Fig.2.2 (Li_Jingjing, 2011).

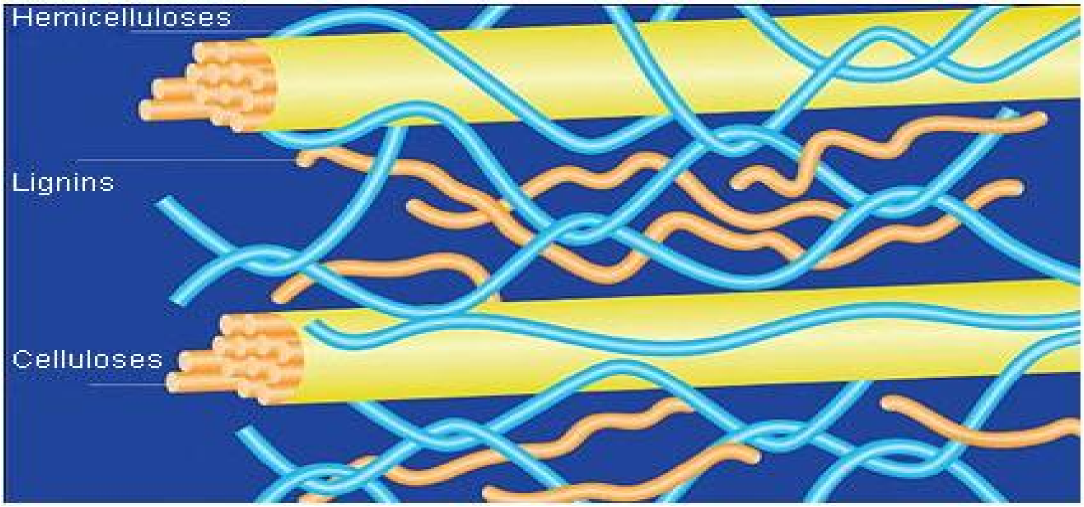


Figure 2.2: The position of lignin within lignocellulosic matrix

Typical results of analyses carried out to determine the compound percentage composition of the various trees are presented in Table 2.1.

Table 2.1: The chemical composition of the various wood species

Constituent (%)	Softwood		Hardwood	
	Scots Pine (Pinus Sylvestris)	Spruce (Piceaglauca)	Silver Birch (Betulaverrucosa)	Eucalyptus (Eucalyptus camaldulensis)
Cellulose (%)	40.0	39.5	41.0	45.0
Hemicellulose (%)	28.5	30.6	32.4	19.2
Lignin (%)	27.7	27.5	22.0	31.3
Total extractives (%)	3.5	2.1	3.0	2.8

(Li_Jingjing)

2.2.5.1 Cellulose

Cellulose (plant fibre) is a polysaccharide consisting of glucose units. It is an insoluble substance in most solvents including strong alkali (Li_Jingjing). The structure of cellulose molecule is illustrated in the Figure 2.3.

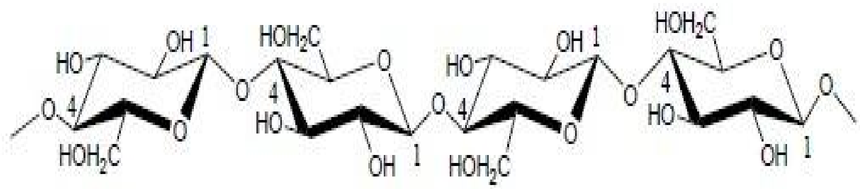
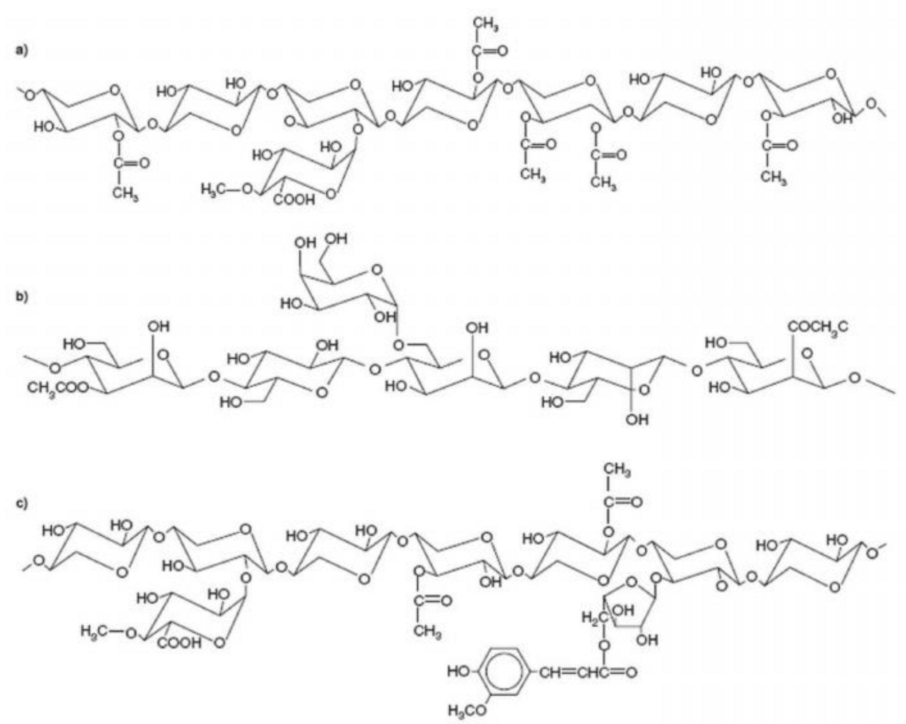


Figure 2.3: The molecular structure of cellulose

Cellulose is the major component of the lignocellulosic materials, representing 40-60% of its total weight in wood. The main function of the cellulose in the plant cell is that it is the structural component. Currently, cellulose is used for paper manufacture (mostly), bioethanol production, artificial fibres (cellulose acetate), plastics (cellulose nitrate), explosives (nitrocellulose), thickeners and gelling agents (cellulose ethers). Examples of cellulose ethers include carboxymethylcellulose, hydroxymethylcellulose and hydropropylmethylcellulose. The degree of polymerization is in the range 10,000-14,000 (Zabaleta, 2012).

2.2.5.2 Hemicelluloses

Hemicelluloses (plant sugars) are amorphous polymers with degrees of polymerization between 100 and 200. They are made mainly from the sugars: D-glucose, D-mannose, D-galactose, D-xylose and L-arabinose. Small amounts of L-rhamnose, 4-O-methyl-D-glucuronic acid, and D-galacturonic acid can be found in some of the hemicelluloses. Some hemicelluloses are acetylated also. The sugars are linearly linked with extensive branches to form the hemicelluloses. The number of branches of hemicelluloses depends on the species and type of wood (Nguyen 2008). Molecular structures of some of the sugars are illustrated in Figure 2.4 (Zabaleta, 2012).



(a) Xylan (hardwood), (b) Glucomannan, (c) Xylan (annual plants)

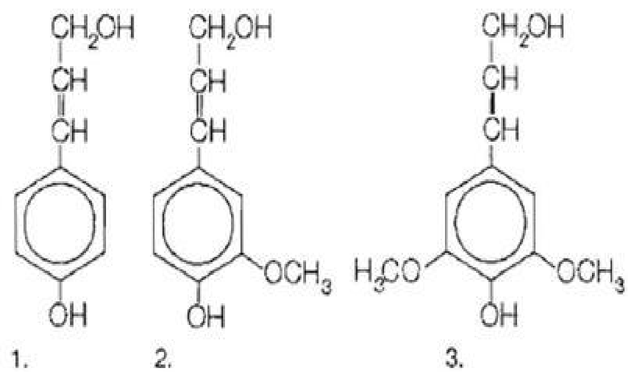
Figure 2.4: Molecular structures of hemicelluloses

2.2.5.3 Lignin

The word lignin is derived from the Latin word “lignum” meaning wood. The main functions of lignin in the plant include acting as the glue between hemicelluloses and celluloses. This imparts rigidity to plant material so that it can resist impact, compression and flexure. Lignin content within species is fairly constant but varies across the species.

(i) Formation of lignin macromolecules

Plants use carbon dioxide ($C0_2$) from the atmosphere in the photosynthesis to produce plant material. Photosynthesis is the transformation of carbon dioxide to carbohydrates using natural light as the energy. The carbohydrates are ultimately transformed into other chemical components, which include phenyl propane lignin precursors (monolignols): p-Coumaryl alcohol, Coniferyl alcohol and Sinapyl alcohol. Molecular structures are illustrated in Figure 2.5 (Kare, 2004).



(1) p-Coumaryl alcohol, (2) Coniferyl alcohol (3) Sinapyl alcohol

Figure 2.5: The molecular structure of lignin

The lignin macromolecule is made by polymerization of these monolignol alcohol monomers.

Nearly all plants contain lignin. Grasses and annual plants lignin (guaiacyl lignin) contain a mixture of p – coumaryl, coniferyl, and sinapyl alcohol monolignols. The soft wood lignin (also referred to as guaiacyl lignin) is mainly composed of coniferyl alcohols, although it contains sinapyl alcohol monolignols in trace amounts. Hard wood lignin (guaiacyl – springyl lignin) contains a mixture of coniferyl and sinapyl alcohols

(Zabaleta, 2012). Atomic mass of a lignin molecule is more than 10,000 Daltons (Da) (Yinghuai, Yuating and Hosmane, 2013). Dalton is the unit of measuring atomic mass, based on carbon 12 isotope: mass of this atom is taken as 12 Da.

(ii) Solubility of Lignin

Lignin is soluble in many solvents, among which are methyl acetate, ethyl acetate, acetone, clorophorm, and dioxane. Lignin that is air-dried after precipitation in water is insoluble in water, ether, benzene, or carbon tetrachloride (Maximova, 2004).

(iii)Lignin applications

Products made from lignin include lignosulfonate (used to control dust on earth roads in residential areas), bioethanol (for blending automobile engine fuels), cement dispersant (plasticizer), vanillin (derivative from lignin), fuel (paper industry), emulsifier (in bitumen), chelating agent (for removing heavy metals from industrial effluents), absorbing agent (lignin is porous) and adhesive resin (Zabaleta, 2012).

2.2.5.4 Extractives

Extractives are soluble in one or more of the following solvents: water, ether, alcohols, acetone, and various simple organic halides. The choice of solvent depends on the type of wood being examined. The solvents should be neutral, and in many cases the extractives can be recovered by evaporating the solutions to dryness. Alkaline or acid organic compounds should not be used, because they attack the cell wall components. Aqueous extraction should be carried out with cold water: hot water causes degradation of the cell wall (Li_Jingjing, 2011).

2.2.5.5 Forest wood resources in Kenya

In section 1.1.2, Kenya’s geographical territory which measures about 582,646 km^2 was discussed. By the year 2011, the fraction of that area under forest cover was 6.07% (World Bank 2011). Forest area is land under natural or planted trees in areas gazetted as forests. This area excludes urban parks and gardens, fruit tree plantations and areas under agro-forestry.

In the years 2010/2011, Kenya timber inventory revealed that 96,357 ha of forest plantations had been stocked with Cypress (54%), Pine (23%), and Eucalyptus (15%) (Kenya Forest Service, 2012). Timber harvested from these forests could not meet the national demand. To supplement the local supplies, in the years 2010/2011, timber imports were made. A volume of 29,100 m^3 of softwood (Cypress and Pine) was imported from Tanzania and Malawi while 5,900 m^3 of hardwood was imported from Democratic Republic of Congo and South Sudan (Kenya Forest Service, 2012).

2.2.5.5.1 Fibre recovery percentages in a sawmill

Wood conversion in Kenya, takes place at the 633 saw mills which have been set up in the country (Kenya Forest Service, 2012). In the conversion process, a typical fibre recovery would was finished timber (47%), chips (34%), saw dust & chip fines (9%), shavings (6%) and shrinkage (4%). Illustration was given in Figures 2.6 and 2.7 (wood products on line expo). It was observed that, at least 15% of the wood mass was converted to shavings and saw dust. In most of the Kenyan sawmills, this 15 % of harvested wood mass go to waste. From this waste, extraction of lignin could have been made and then converted into lignosulphonate plasticizing concrete admixtures in significant quantities for the local construction industry.

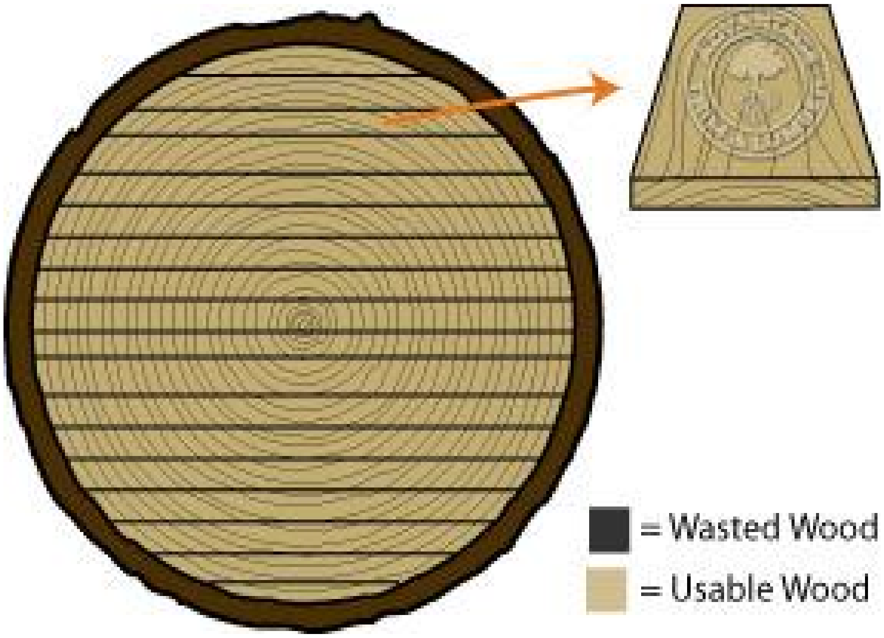


Figure 2.6: Plain sawn timber

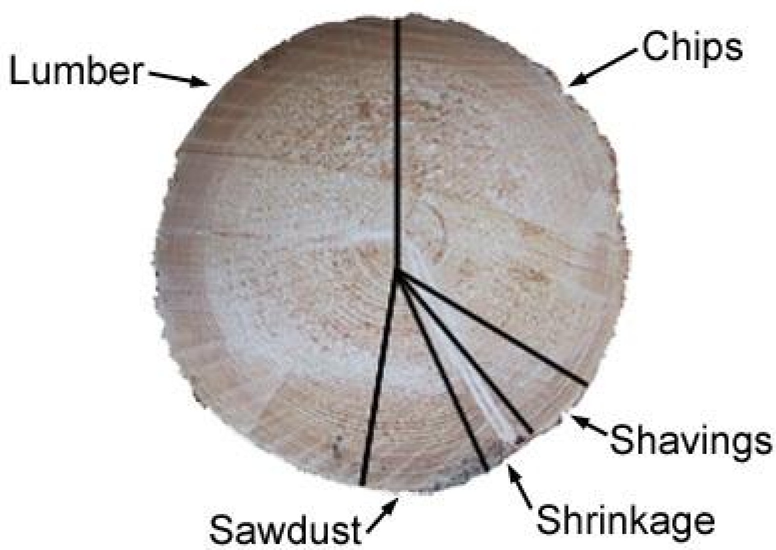


Figure 2.7: Typical fibre recovery percentages in softwood sawmill

2.2.6 Aggregates

The aggregate is used primarily for the purpose of providing bulk to the concrete. It provides about 75% of the body of the concrete. Aggregate is cheaper than cement and it is, therefore, economical to put into the mix as much of the former and as little of the latter as possible. In addition, aggregate has higher volume stability and better durability than hydrated cement paste alone (Neville, 201).

Classification of aggregates is based on origin, particle size, particle shape, unit weight, and surface texture (Gambhir, 1990). The origin of the aggregates may be classified as either natural or artificial. The two types of natural sources of aggregates are the natural deposit of sand and gravels (pits and river beds) and stone quarries. Aggregates from pits and river beds are cheaper since reduction in size has been done by natural agents such as water, wind or glaciers. River deposits are the most common and have good quality aggregates. Nearly always fine aggregates in Kenya are from these sources. In the quarries, aggregates are produced by mining the rock and crushing it to the required sizes. Coarse aggregate has maximum and minimum sizes of 40 mm and 5 mm, respectively. Fine aggregate maximum and minimum sizes are 5 mm and 0.075mm, respectively. The right grading of the coarse aggregates is achieved by screening at the crushing stage. Coarse aggregates are mainly obtained by mining rock and crushing it to the required sizes. Natural rocks can be classified according to their mode of geological formation (Blyth & de Freitas, 1974). These classes of rock are igneous, sedimentary, and metamorphic.

In general, aggregates to be used in concrete must be clean, hard, properly shaped, well graded, possessing chemical stability, resistant to abrasion, resistant to freezing and thawing, not be possessing deleterious material which may cause physical or chemical changes such as cracking, swelling, and softening. The strength of concrete cannot exceed that of the aggregates and therefore aggregates should always be stronger than the concrete they are supposed to produce.

Ten percent fines value test is one of the tests used to assess the suitability or otherwise of coarse aggregates in terms of strength (BS 812-111:1990). The test measures resistance to pulverization of aggregates. The aggregates to be tested should pass a 14.0 mm sieve and be retained on a 10.0 mm sieve. The sample to be tested is dried in an oven at 100 to 110^{o} C for 4 hours and then placed in a cylindrical mould in three equal successive portions. Each portion is given 25 tamping blows, using a 16 mm diameter x 600 mm long standard steel rod, evenly spread out over the whole surface. The rod is raised 25 mm above the surface of the aggregates and released to fall under gravity, to constitute a blow. A plunger is put on top of the aggregates and the whole assembly is placed in a compression testing machine and subjected to a progressively increasing load so as to cause a penetration, in 10 minutes, of about 20 mm (in crushed aggregates).This penetration should result in a percentage of the fines passing a 2.36 mm sieve of between 7.5% and 12.5%. If y is the actual percentage of fines due to a maximum load of x tons, then the load required to give 10 per cent fines is given by the formula (BS 812-111:1990):

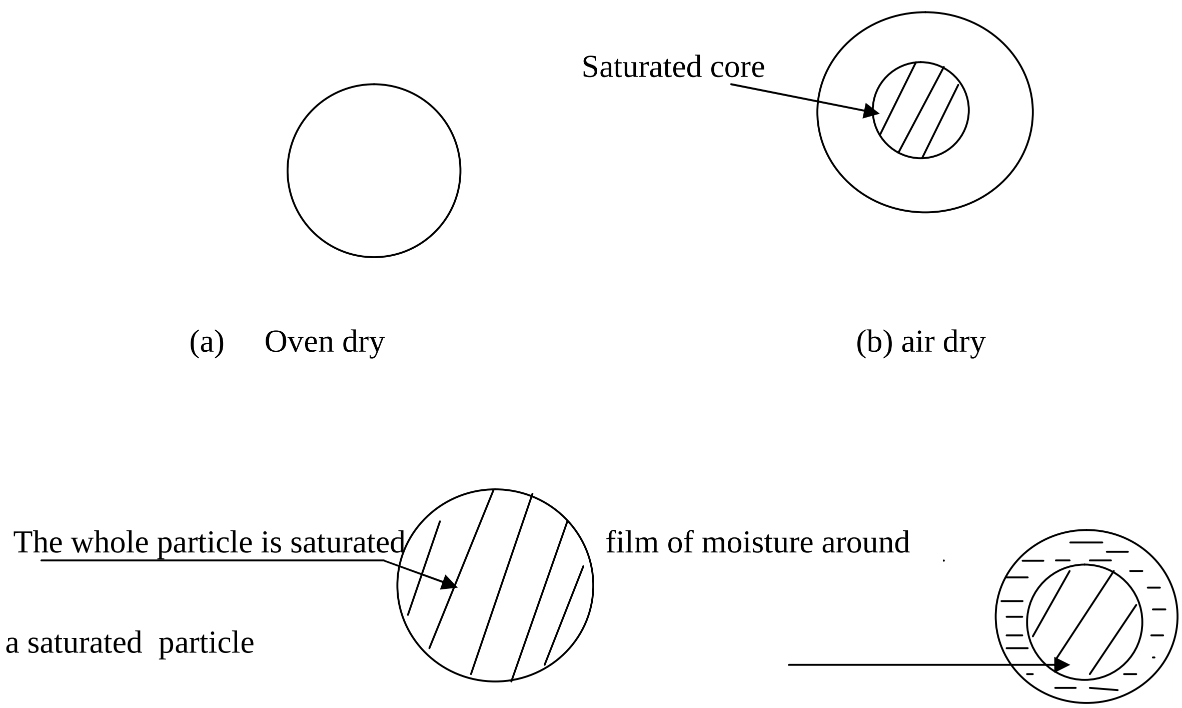
$$The\ ten\ percent\ fines\ value\ x_{10} = \frac{14\ (x)}{(y+4)} \qquad (2.3)$$

A higher numerical result denotes a higher strength of the aggregates. The BS 882:1992 prescribes a minimum value of 150 kN for aggregates to be used in heavy – duty concrete floor finishes, 100 kN for concrete to be used in pavements wearing surfaces and 50 kN when used in other concretes.

The particle size distribution of aggregates is determined by sieve analysis test. For coarse aggregates this information is used to check the compliance with the recommended grading, and for fine aggregates to determine the percentage passing the 0.600 mm standard sieve, the grading curve, and fineness modulus (BS 812-103.1:1985).

In connection with moisture content of aggregates, the terms oven dry, air dry, saturated and surface dry (SSD), and wet are used. Oven dry refers to particles that are completely dry for all practical purposes. Air dry refers to aggregates that are dry at the surface though containing some moisture but less than the amount required to saturate the aggregate particles. In this condition, an aggregate can absorb more water into itself and may still appear dry on the surface. The absorbed moisture plays no part in lubrication of mixed concrete. Saturated and surface dry (SSD) refers to the aggregate particle that can absorb no more water without a film of water forming on the surface. The particle neither contributes to nor absorbs water from the concrete.

Wet aggregate refers to a saturated particle that also carries an excess of moisture forming a film on the surface of the particle. Fig. 2.8 is an illustration of these definitions (Murdock & Brook, 1979).



(a) Oven dry (b) air dry

(c) Saturated surface dry (SSD) (d) wet

Figure 2.8: Moisture conditions in aggregates

(a) Oven dry- no moisture.

(b) Air dry - water less than absorption capacity.

(c) Saturated surface dry (SSD) - moisture equal to absorption capacity.

(d) Wet**:** moisture content greater than absorption capacity.

The moisture content of an aggregate when it is in saturated surface dry (SSD) condition is referred to as its water absorption. In a wet condition an aggregate particle contains sufficient water for absorption and excess water to form a film of moisture around the particle. The amount of water in excess of absorption is referred to as moisture content. Total water content for an aggregate particle is absorption plus moisture content.

2.2.7 Water for concrete

Some of the water added at the concrete mixer is absorbed by the fine and coarse aggregate particles to bring them to the SSD condition. The absorbed water does not participate in lubrication of aggregate particles or in the cement hydration. Water for absorption by aggregates should be determined in the laboratory and an allowance made for it in the mix design calculations.

Full hydration of cement requires a mass of water equal to about 38% of cement mass (Kong & Evans, 1985). Hydration of the cement particle starts from the outer surface and progresses towards the centre. The hydration results in a layer of hydration products that progressively inhibit water from reaching the unhydrated inner part of the cement particle. When the layer reaches a thickness of about 25 µm, hydration process completely stops. Therefore any cement particle with a diameter greater than 50 µm will have an unhydrated inner core after hydration stops. The size of the cement grains in ordinary Portland cement is in the range 5 -55 µm **(**Soroka, 1979).

Hence, in practice, complete hydration of cement does not take place. Under practical conditions, cement chemically combines with a mass of water equal to about 23% of its mass. This amount of water is referred to as non-evaporable water. Concrete with a free-water/cement ratio of 0.23 is too difficult to work and therefore, additional water is required to lubricate the mix. After placing concrete, water in excess of what is required for hydration (evaporable water) evaporates when the concrete dries out. The spaces left after the loss of the evaporable water and the spaces occupied by any air bubbles trapped in the concrete mix are collectively known as voids. The presence of voids lowers the concrete strength as illustrated in Fig. 2.9 (Murdock & Brook, 1979). For this reason, the evaporable water should be kept to a minimum.

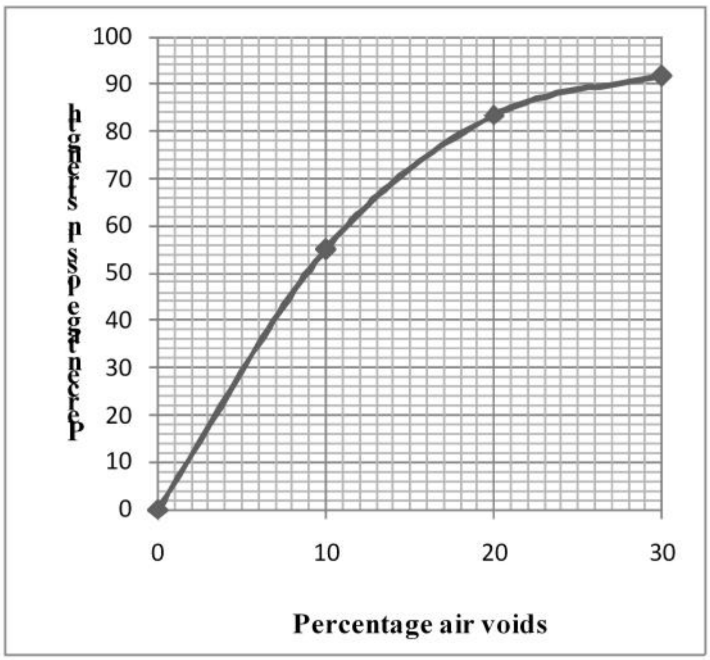


Figure 2.9: Loss of strength versus air voids in hardened concrete

If water is suitable for drinking, it is generally suitable for concrete making. If water is suspected to be unsuitable, two series of test cubes may be made: one series with the suspected water and the other with drinking water. The strengths and general appearances at 7 and 28 days will provide useful information. Effluents from sewerage works, paint industry, textile industry, sugar industry, fertilizer industry, and excessive amount of dissolved salts reduce compressive strength of concrete by up to 30%. Sea water increases the corrosion of the reinforcing steel (Gambhir, 1990).

2.2.8 Cements

Ancient building structures were composed of earth, raised in the form of walls or domes by ramming successive layers. Sometimes, the structures would be made of stone blocks, set one above another without the aid of any cementing material as in the cyclopean masonry of Greece (Neville, 2011). The earliest bonded masonry walls are found in the brick walls of ancient Egypt. The bricks were dried in the sun without baking, and each course was covered with a moist layer of the loam (Nile mud) used for making the bricks, with or without the addition of chopped straw. The drying of this layer made the wall a solid mass of dry clay. Such a mode of construction is only possible in a rainless climate, as the unburnt material possesses little resistance to water. It has nevertheless persisted throughout the ages (Neville, 2011).

Burnt bricks were employed by the Babylonians and Assyrians and were cemented together with bitumen. This method was very effective, but remained confined to the regions where there were natural deposits of bitumen (Neville, 2011). The present day mortar, consisting of a mixture of sand and cementitious material, first occured in the massive masonry constructions of the Egyptians. The cementing materials were always obtained by burning gypsum rather than the lime. Gypsum rock ($CaSO_4.2H_2O$) is available in natural deposits and it is from one of these, the hill of Montmartre in Paris, that the name Plaster of Paris is derived. Finely ground gypsum is heated to obtain Calcium Sulphate hemihydrates (Neville, 2011):

$$CaSO_4.2H_2O + HEAT\ (150^oC) \longrightarrow (CaSO_4.1/2H_2O) + 11/2H_2O \qquad (2.4)$$

Calcium Sulphate hemihydrates ($CaSO_4.1/2H_2O$), a powder, is the ordinary plaster of Paris. When it is mixed with water, the reaction is reversed (Neville 2011):

$$CaSO_4.1/2H_2O + 11/2\ H_2O \longrightarrow CaSO_4.2H_2O \qquad (2.5)$$

Calcium sulphate hydrate ($CaSO_4.2H_2O$) is cementitious but is not stable in water and can only be classified as a non-hydraulic cement.

If calcium sulphate hemihydrate is farther heated, complete dehydration occurs:

$$CaSO_4.1/2H_2O + HEAT\ (200^oC) \longrightarrow CaSO_4 + 1/2H_2O \qquad (2.6)$$

Lime is obtained from calcium carbonate which occurs naturally as marble, chalk, and limestone. When heated to a temperature of 894^{o}C, calcium carbonate decomposes to calcium oxide (quick lime) and carbon dioxide.

$CaCO_3$ + HEAT (894^{o}C) $\longrightarrow$ (Calcium Oxide or quick lime) $CaO + CO_2$ (2.7)

$CaO + H_2O$ $\longrightarrow$ (Calcium Hydroxide or slaked lime) $Ca(OH)_2$ + heat (2.8)

Calcium hydroxide is also a cementitious material but is not able to set and harden in water and may also, therefore, be referred to as non-hydraulic cement (Soroka, 1979).

The reason for using gypsum instead of lime, although limestone was more abundant and more accessible than gypsum was the scarcity of fuel, calcination of limestone requiring higher temperature.

Use of lime might have started in Crete and was later used in Greece. The Romans must have borrowed it from Greece. There is evidence that crushed burnt clay was added to lime mortar to give it hydraulicity in the Minoan civilization of Crete; since lime mortar does not harden under water. It seems that the Romans may have used crushed tile additions before they discovered the natural pozzolana. The Greeks and the Romans later learned to add to lime and water sand and crushed stones or sand and crushed bricks or sand and broken tiles. This was the first concrete in the history of civil engineering (Neville, 2011).

In order to form hydraulic cement for under water construction the Romans ground together lime and volcanic ash and when this was not available, lime and burnt clay tiles. The volcanic ash was found at different points in and near the bay of Naples (Italy). As the best variety of this earth was obtained from the neighbourhood of Pozzuoli (or Pozzoli) the material acquired the name Pozzolana or Pozzolan. To make hydraulic mortar, the Greeks used tuff (consolidated volcanic ash) from the island of Thera (now known as Santorin) and this material known as Santorin earth is still in use today in the Mediterranean. After the collapse of the Roman Empire, the quality and use of lime mortar declined (Neville, 2011).

2.2.8.1 Manufacture of Portland cement

In 1756 John Smeaton, while constructing Eddystone light house, off the Cornish coast (UK), found out that the best mortar was produced when lime was made from limestone containing a high proportion of clay matter, which, before this date had been considered undesirable. For the first time, the important role played by clay in production of hydraulic cement was recognized. In 1796, Roman cement was made by Joseph Parker, by calcining of argillaceous limestone (limestone containing clay with silica and alumina) (Neville, 2011).

On 21/10/1824, Joseph Aspdin, a Leeds (UK) builder, took a patent of the Portland cement which he had made by heating a mixture of finely ground clay and hard limestone in a furnace until CO_2 had been driven off. It is now known that this happens at a temperature range of 850^oC–900^oC which is lower than the temperature required for clinkering and hence the cement must have been inferior in strength. The prototype of the modern Portland cement was made by Isaac Charles Johnson in 1845 by burning a mixture of clay and chalk until clinkering, so that the reactions necessary for the formation of strongly cementitious compounds took place. The name Portland cement was given due to the resemblance of the colour and the strength of set cement to Portland stone (a limestone quarried in Dorset – UK) (Neville, 2011).

Cement may be defined as a material with adhesive properties which make it capable of bonding mineral fragments into a compact whole. For constructional purposes the meaning of the term cement is restricted to bonding materials used with stones, sand, bricks, building blocks, etc.

These cements have the property of setting and hardening under water as a result of a chemical reaction with water. They are therefore referred to as hydraulic cements and include Portland cement. Hydraulic cements consist, mainly, of silicates and aluminates of lime.

The Portland cement is made from calcareous materials (materials containing $CaCO_3$ such as limestone and chalk) and argillaceous materials (materials containing silica and alumina such as shale) (Neville, 2011). Marl (a mixture of calcareous and argillaceous materials) may also be used. The process of cement manufacture consists of grinding raw materials, mixing them intimately in certain proportions and burning in a large kiln at a temperature of 1300 – 1400^{o}C. At this temperature, materials chemically react together and fuse into balls known as clinkers. Clinkers are cooled and ground to a fine powder with some gypsum added. The mixing and grinding of the raw materials can be done either in water or in a dry condition hence the names wet and dry processes.

The mixed material is fed at the upper end of a slightly inclined and rotating kiln. Pulverized coal is blown into the kiln at the lower end with temperature at 1400 – 1500^{o}C. Up to 350 kg of coal is required for each 1000 kg of cement to be manufactured (Neville, 2011). Oil or natural gas can also be used instead of coal. Finally 20% – 30% of the material melt into liquid at which stage lime (CaO), silica (SiO_2), and Alumina (Al_2O_3) combine. The mass then fuses into balls 2 mm – 3 mm in diameter (the clinkers). After cooling, clinkers are interground with gypsum (to prevent flash setting of cement). Grinding is done in a ball grinding mill to fineness of the order of 1.1 x 10^{12} particles / kg (specific surface – 350 m^2 /kg) before bagging (Neville, 2011).

Ordinary Portland cement is the most commonly used type of Portland cement: about 90% of the cement used in construction industry is OPC (Neville, 2011). The rate of hydration of cement depends on the fineness of the cement particles and for a rapid development of the strength, high fineness is necessary. Fineness is therefore an important property of cement and has to be carefully controlled.

2.2.8.2 Oxide composition of Portland cement

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina, and iron oxide. Typical percentage contents of these oxides were given in Table 2.2.

Table 2.2: Approximate oxide composition limits of ordinary Portland cement

oxide	Percentage content
Lime (CaO)	60 - 67
Silica (SiO_2)	17 – 25
Alumina (Al_2O_3)	3.0 – 8.0
Iron oxide (Fe_2O_3)	0.5 – 6.0
Magnesia (MgO)	0.1 – 4.0
Alkalies (K_2O, Na_2O)	0.4 -1.3
Sulphur trioxide (SO_3)	1.3 -3.0

(Shetty, 2009)

2.2.8.3 The major constituent compounds of Portland cement

The oxides of cement interact with one another in the kiln at high temperature to form more complex compounds. The major constituent compounds so formed are presented in Table 2.3.

Table 2.3: Major constituent compounds of cement (Bogue's compounds)

Name of compound	Formula	Abbreviated formula
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalciumaluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

(Soroka, 1979)

2.2.8.3.1 Calculation of proportions of the major constituents of Portland cement

The percentage composition may be calculated from the equations presented in Appendix B. For the more common case [Alumina: Ferric oxide ratio ≥ 0.64 (Al_2O_3 / Fe_2O_3 ≥ 0.64)], the equations are:

(a) Tricalcium silicate:

$$C_3S = 4.071CaO - (7.600SiO_2 + 6.718Al_2O_3 + 1.430Fe_2O_3 + 2.852SO_3) \quad (2.9)$$

(b) Dicalcium Silicate: $C_2S = 2.867\ SiO_2 - 0.7544\ C_3S$ (2.10)

(c) Tricalcium Aluminate: $C_3A = 2.650\ Al_2O_3 - 1.692\ Fe_2O_3$ (2.11)

(d) TetracalciumAluminoferrite: $C_4AF = 3.043\ Fe_2O_3$ (2.12)

In equations (2.9) - (2.12), CaO, SiO_2, Al_2O_3, Fe_2O_3, and SO_3 represent the oxide mass percentage contents as may be determined by a chemical analysis (Soroka, 1979).

2.2.8.4 The minor constituent compounds of Portland cement

The minor constituent compounds are gypsum ($CaSO_4.2H_2O$), free lime (CaO), magnesia (MgO), alkali oxides (K_2O, Na_2O), titanium oxide (TiO_2), and phosphorus pentoxide (P_2O_5). The combined mass percentage of these compounds has a maximum value of the order of 2% of the mass of cement.

2.2.8.4.1 Gypsum

Gypsum is added during the grinding of the clinkers in order to slow down the hydration process of tricalcium aluminate. Tricalcium aluminate (C_3A) hydrates instantaneously, resulting in rapid setting. Gypsum reacts with C_3A to form a layer of ettringite ($3C_3A.3CaSO_4.31H_2O$) on the surface of the C_3A grains which slows the hydration process. Further hydration involves the diffusion of water through the ettringite layer. However, while the formation of ettringite is desirable in fresh mixes, it involves volume expansion, and should therefore be avoided in hardened concrete. When only a small amount of gypsum is present, ettringite is formed when the concrete is in plastic state and hence concrete takes the volume increase without sustaining damage. Consequently, to avoid cracking and damage, BS 12 specify a maximum SO_3 content of 2.5% for cements with C_3A content not exceeding 7%, and 3% for cements having a C_3A content exceeding 7%.

2.2.8.4.2 Free lime (CaO)

Uncombined lime in cement may occur when the raw materials, used in the manufacturing process contain more lime than can combine with the oxides SiO_2, Al_2O_3, and Fe_2O_3. Alternatively it may occur when the amount of lime in the raw materials is not excessive, but when its reactions with the said oxides are not complete after the clinkering process. Hydration of free lime is expansive and could result in cracking, if it occurred in hardened concrete. To control the amount of free lime BS 12 specifies that lime saturation factor (LSF) should have minimum and maximum values of 0.66 and 1.02, respectively. Lime saturation factor:

$$LSF = (CaO - 0.7SO_3) / (2.8\ SiO_2 + 1.2\ Al_2O_3 + 0.65Fe_2O_3) \qquad (2.13)$$

Where CaO, SiO_2, Al_2O_3, Fe_2O_3, and SO_3 represent the oxide mass percentage contents as may be determined by a chemical analysis.

2.2.8.4.3 Magnesia (MgO)

The raw materials for Portland cement contain a certain amount of magnesium carbonate ($MgCO_3$) which on heating dissociates to magnesia (MgO) and carbon dioxide (CO_2). Magnesia does not combine with the major oxides SiO_2, Al_2O_3, and Fe_2O_3. Hydration of MgO is similar to that of CaO resulting in volume increase. BS 12 limits MgO content to 4%.

2.2.8.4.4 Alkali oxides (K_2O, Na_2O)

These oxides are introduced into the cement through the raw materials and their content varies from 0.5% to 1.3%. If alkali reactive aggregates are used for concrete production, alkali-silica gel is formed in an expansive reaction leading to cracking and destruction of concrete. For this reason, the total alkali content of cement should be limited to 0.6%.

2.2.8.4.5 Titanium oxide (TiO_2)

Titania (TiO_2) is introduced into the cement through the clay or shale used in the manufacture. Its content varies from 0.1% to 0.4%.

2.2.8.4.6 Phosphorous pentoxide (P_2O_5)

It is introduced into cement through the limestone used in its manufacture. Its content does not exceed 0.2%. Its presence breaks down C_3S to C_2S and CaO. This slows down the strength development. Lager amounts of P_2O_5 may cause unsoundness because free lime is formed.

2.2.8.5 Hydration of Portland cement

When cement is mixed with water, the major constituent compounds of cement hydrate. The hydration equations were presented in Appendix C. Cement strength is mainly from hydration of tricalcium silicate and dicalcium silicate as illustrated in Fig.2.10 (Soroka, 1979).

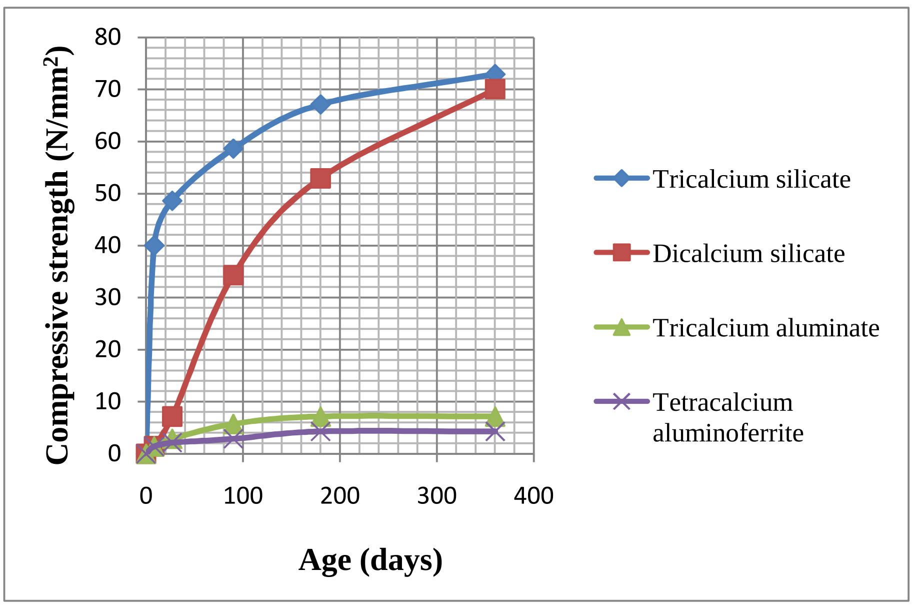


Figure 2.10: Compressive strength of the major constituents of Portland cement

2.2.8.5.1 Hydration of tricalcium silicate ($3CaO.SiO_2$)

$$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \qquad (2.14)$$

Molar proportions:

$2(3CaO.SiO_2)$ + $6H_2O$ $\longrightarrow$ $3CaO.2SiO_2.3H_2O$ + $3Ca(OH)_2$

456 108 342 222

Hence, hydration of tricalcium silicate (C_3S):

(i) Produces (342) (100)/ (342+222) = 60.6 % = 61 % Calcium silicate hydrate (C - S - H),

(ii) Produces (222) (100)/ (342 + 222) = (222) / (564) = 39.4 = 39 % calcium hydroxide,

(iii) Requires an amount of water = (108) / (456) = 23.7 = 24 % of its own weight for full hydration.

This reaction is exothermic: heat evolved =500 J/g (Soroka, 1979).

2.2.8.5.2 Hydration of dicalcium silicate ($2CaO.SiO_2$)

$2(2CaO.SiO_2) + 4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$ (2.15)

Molar proportions:

$2(2CaO.SiO_2)$ + $4H_2O$ $\longrightarrow$ $3CaO.2SiO_2.3H_2O$ + $Ca(OH)_2$

344 72 342 74

Therefore hydration of dicalcium silicate (C_2S):

(i) Produces (342)(100) / (342 + 74) = 82 % Calcium silicate hydrate

(ii) Produces (74)(100) / (342 + 74)= 18 % Calcium hydroxide

(iii) Requires an amount of water = (72) (100)/ (344) =21 % of its own weight for full hydration.

This reaction is exothermic: heat evolved =250 J/g (Soroka, 1979).

The hydration of the silicates results in calcium silicate hydrate and calcium hydroxide. Calcium silicate hydrate binds solid particles into a compact whole. It is the hydration product, largely, responsible for the strength gain of concrete (Soroka, 1979).

2.3 Past research on plant extracts

2.3. 1 Coconut plant

U S Sarma, and Anita Das Rabindranath (Sarma & Rabindranath, 2003), both of Central Research Institute (Coir Board), Kerala, India, have reported on the investigations they carried out on extraction of sodium lignin sulphonate from coconut coir pith. In the study, pith was extracted from coconut husks and then digested in an autoclave at 115^{o}C for 30 minutes and then the temperature was raised to 135^{o}C for 90 minutes. Before putting the material into the autoclave it was mixed with 2% solution of sodium bisulphite. The coir pith material to solution ratio was 1:10, respectively. The pH of the mixture was maintained at an acidic range by use of dilute hydrochloric acid.

In this process, lignin reacts to form solid lignosulphonic acid which then dissolves in the liquor. In solution, it combines with sodium to form soluble sodium lignin sulphonate in the black liquor. The sodium lignin sulphonate extract was concentrated under low pressure using a Rota Vap Aspirator Model A-35. A 325 ml sample of the concentrated black liquor yielded 6.0 g of lignin sulphonate powder (1.85%).

Uses of sodium lignin sulphonate include making of concrete plasticizers (dispersants), road binder, briquette binder, drilling mud additive, and grinding aid (Sarma & Rabindranath, 2003).

2.3.2 Acacia (Hashab: Arabic) tree extract

Use of plant extracts in concrete as admixtures has been studied by many scholars. Gum Arabic (Acacia tree extract) was used as an admixture in concrete, at the various dosage levels, expressed as a mass percentage of cement content. Both powder and liquid forms of the extract were studied (Abdeljaleel, 2012). The research findings were that, for both physical forms of the extract, the significant dosage was 0.4% of the cement content, a reduction in compressive strength, proportional to the dosage, occurred in both cases, and that Gum Arabic in liquid state, gave increased values of slump of fresh concrete mixes.

2.3.3 Indian Bamboo (Bambusa Arundinacea)

In a research involving this plant, the effectiveness of an extract from it as a reinforcing steel corrosion inhibitor was studied. For the study, four concrete mixes A, B, C, and D were involved. For all the mixes a normal concrete mix design was carried out in accordance with DOE method (Abdulrahman, 2011). For all the mixes, the characteristic strength was 30 N/mm^2, ordinary Portland cement was used, w/c ratio was 0.45, workability was maintained at the range 30 mm to 60 mm slump, and the wet mix density attained was 2380 kg/m^3. Table 2.4 is a presentation of the mix design summary.

Table 2.4: Normal concrete mix design output summary

Cement content (kg/m^3)	Water content (kg/m^3)	Fine aggregates content (kg/m^3)	Coarse aggregates content (kg/m^3)
511	230	623	1016

(Abdulrahman, 2011**)**

In all concrete specimens, reinforcing steel bars were embedded during casting. Mix A was used as a control. During mixing magnesium chloride ($MgCl_2$) was introduced into mixes B, C, and D to induce corrosion in the embedded steel. The mass of magnesium chloride added was 1.5% of the mass of the cement. Calcium nitrite $Ca\ (NO_2)_2$, a corrosion inhibitor in concrete, was added into mix C. The quantity of $Ca\ (NO_2)_2$ added was 2% of the mass of cement. Into mix D was added a plant extract from Indian Bamboo (Bambusa Arundinacea). The mass added was 2% of the mass of cement.

(a) Preparation of the plant extract

Fresh leaves of Bambusa Arundinacea (Indian Bamboo) were washed under running water, shade dried, and ground into powder. Plant extract was obtained using 95% ethanol. 5 g of powdered leaves were soaked in 200 ml of the ethanol for 14 days and thereafter filtered. In order to leave the sample free of ethanol, the filtrate was subjected to evaporation using a rotary evaporator.

(b) Corrosion testing

The concrete samples were cast in 100 mm cube moulds. The specimens were demoulded after 24 hr and wet curing in sea water for 28 days followed, for specimens from mixes B, C, and D. Control concrete was cured in potable water bath for 28 days. Corrosion of the embedded metal was measured after 180 days of exposure to wet and dry cycles. The measurements were done using electrochemical impedance spectroscopy and linear polarization resistance.

(c) Results:

1. Comparison of corrosion observations from mixes A, B, C, and D confirmed that corrosion had been initiated in the metals embedded in mixes B, C, and D and that no corrosion had occurred in metal embedded in mix A

2. Comparison of corrosion observations from mixes B, C, and D revealed that corrosion was inhibited in mixes C and D and that the plant extract (added to mix D) was a more effective inhibitor of metal corrosion than calcium nitrite incorporated in mix C (Abdulrahman, 2011).

2.4 Summary

2.4.1 Housing

Shortage of housing in Kenya was cited in section 1.2 of this report: By the year 2004, annual national demand for homes was estimated at 450,000 against a supply of 30,000 - 50,000. Some of the factors adversely affecting housing development were discussed in section 1.1.2. The factors cited were high cost of building materials, poverty, high population growth rate, high rate of urbanization, high land prices, inadequate and costly finance and rigid construction regulations.

2.4.2 Building materials

In section 1.3, concrete was cited as the mostly used building construction material. The main ingredients of concrete are aggregates, cement, water and admixtures. It was further established that, materials only, cost of cement in mass concrete was 70%. This led to the conclusion that improving performance of cement, so that less of it was required, was the most effective way of reducing cost of mass concrete.

2.4.2.1 Cement

(a) Function of cement in concrete

The main role of cement is to provide strength in the hardened concrete. However, it has a subsidiary function in hardened concrete of providing an alkaline environment that inhibits corrosion of steel reinforcement in reinforced and pre-stressed concretes. On account of its high degree fineness, cement plays another subsidiary function in fresh concrete of increasing the workability.

(b) Chemical composition

Cement is a mixture of major and minor constituent compounds:

(i) Major constituent compounds

These compounds are tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite.

(ii) Minor constituent compounds

The compounds are gypsum, lime, magnesium oxide, titanium oxide, alkali oxides, and phosphorous pentoxide. These compounds originate from the raw materials. Gypsum, lime, alkali oxides (potassium oxide and sodium oxide) and magnesium oxide in hardened concrete undergo expansive chemical reactions that resulting in cracking and disintegration of hardened concrete. Phosphorous pentoxide has the effect of converting tricalcium silicate into dicalcium silicate and thus slowing down the strength development of concrete.

(c) Hydration of the major constituent compounds of cement

The hydration of tricalcium silicate is given in the chemical equation (2.14) and that of dicalcium silicate in equation (2.15). The chemical reactions for the hydration of tricalcium aluminate and tetracalcium aluminoferrite are given in equations (C3) and (C4), respectively, of Appendix C. The reaction products are responsible for the strength gain of concrete. The relative strength values from the hydration of the four different major constituent compounds are shown in Figure 2.10. From Figure 2.10, it was inferred that the strength development is largely attributed to hydration of tricalcium silicate and dicalcium silicate. The hydration products of the silicates are calcium silicate hydrate (C-S-H) and calcium hydroxide $Ca(OH)_2$. Calcium silicate hydrate is the compound responsible for strength development.

The hydration reactions take place when cement grains are in contact with water. The greater the area of contact, the higher the rate of hydration, and therefore, the higher the rate of strength development. Considerations limiting fineness of cement include cost of grinding and shelf life. Shelf life decreases with the increase in the fineness.

(i) Physical aspects of hydration

Cement grain sizes and hydration physical process are discussed in section 2.2.7. In summary, high degree of fineness in cement optimizes:

1 The rate of strength development,
2 The fraction of the cement content that gets hydrated,
3 The workability of the wet mix.

The main disadvantage of the high degree of fineness is flocculation. As discussed in section 2.2.4, flocculation of cement grains in wet concrete mixes results in high free-water/cement ratios and subsequent low strengths in hardened concrete. Plasticizing admixtures are incorporated in the mixes to alleviate this disadvantage.

2.4.2.2 Plasticizing admixtures

To prevent the flocculation of cement, in wet mixes, plasticizing admixtures are used. Examples of plasticizers include sodium lignin sulphonate, calcium lignin sulphonate, magnesium lignin sulphonate, and ammonium lignin sulphonate. These admixtures are collectively referred to as lignosulphonates. The active ingredient in these admixtures is lignin. Over 90% of plant biomass is made of the compounds cellulose (fibres), hemicelllulose (plant sugar), and lignin. The cations such as Na^+ and Ca^+ are introduced during the extraction of lignin from the biomass to improve extraction effectiveness. The extract so obtained is mainly a mixture of lignin and hemicellulose. Hemicelluloses have the effect of retarding hydration of cement. Purification process separates lignin and hemicellulose. Lignin has limited solubility in water. Sulphonation is done to improve solubility of lignin in water.

2.4.2.2.1 Lignosulphonate working mechanism

The lignin radical in the lignosulphonate is negatively charged. When the admixture is used in concrete, the lignin radicals get adsorbed onto the cement particles making all the cement particles to, effectively have the same negative charge. This results in repulsive forces between the cement particles. The net effect is that the cement particles are dispersed. The water which had been trapped by flocculation becomes freely available for lubrication. In addition, after dispersion, friction between particles is greatly reduced. The result is increased workability.

In the flocculated state, the particles contact surfaces are not readily available for hydration. After dispersion, these areas come into contact with water resulting in hydration. As a consequence, the rate of hydration increases. Dispersion leads to even distribution of the cement particles throughout the body of the concrete. Even distribution of cement particles raises their concentration in areas of relative deficiency.

Thus although the admixture does not increase the strength of the cement, strength of the structural concrete member is increased.

2.4.3 Past research

Research activities in plant extracts were discussed in section 2.3. The cited plants were Acacia, Coconut and Indian Bamboo (Bambusa Arundinacea). Work on Acacia and Coconut plants was considered directly relevant to this study.

2.4.3.1 Acacia (Hashab: Arabic) tree extract

Gum Arabic (Acacia tree extract) was used as an admixture in concrete, at the various dosage levels, expressed as a mass percentage of cement content (Abdeljaleel, 2012). Both powder and liquid forms of the extract were studied. The research findings were that:

1. For both physical forms of the extract, the significant dosage was 0.4% of the cement content,
2. A reduction in compressive strength, proportional to the dosage, occurred in both cases. At a dosage of 0.4%, 28 days compressive strength reductions were 9% and 8% with powder and liquid forms of the extract, respectively.
3. Gum Arabic in liquid state, gave increased values of workability of fresh concrete mixes. At a dosage of 0.4%, the slump of the concrete containing the admixture was 70 mm while that for the control concrete was 15 mm.

2.4.3.2 Coconut plant extract

Coconut coir pith was extracted and converted into sodium lignin sulphonate. Uses of sodium lignin sulphonate include making of concrete plasticizers (dispersants), road binder, briquette binder, drilling mud additive and grinding aid.

2.5 The research gaps

In section 2.3, case studies on Coconut and Acacia plant extracts were reviewed. In the two cases, the researchers made studies on plant materials that were available in their respective countries. In like manner, plant materials, widely and abundantly obtainable in Kenya (Cypress, Pine and Eucalyptus) were the subject of this study. Discussion of plant species in Kenyan forests, in section 2.2.5, showed that in the years 2010/2011 stocking was Cypress (54%), Pine (23%), and Eucalyptus (15%). Acacia and coconut plants are also available in Kenya but they are mainly limited to arid and coastal regions, respectively.

2.5.1 Acacia plant extract

Thorough investigations on the effects of Acacia extract on the workability of fresh concrete and compressive strength of hardened concrete were made (Abdeljaleel, 2012). The methodology involved converting the purest form of Gum Arabic (Acacia plant extract) into powder and water solution. The extraction procedure of the gum from the biomass was omitted in that report. Extraction process is a major consideration in determining the practicability and viability of the subsequent admixture. In this study, the extraction processes were covered.

2.5.2 Coconut plant extract

For the coconut plant extract, chemical extraction procedure was followed. Sodium bisulphate and dilute hydrochloric acid were used to make extraction of lignin from the plant biomass more effective. Use of chemicals is a more expensive procedure than use of water, heat and pressure as was done in this study. The report on the research carried out by Sarma and Rabindranath did not contain any information on concrete laboratory trials to determine the effect of the admixture on the properties of concrete. In this research, the trials were carried out.

CHAPTER THREE

METHODOLOGY

3.1 Plants under study

In this study, three plants were involved**:** cypress, pine, and eucalyptus (International centre for research in Agro-forestry, 1992). The selection was made on the basis of availability. The three plants are some of the most widely grown in Kenya for timber production. Two different extracts were made from each plant: one from the bark and the other from the wood. Pieces of the bark or wood chips together with tap water were put into a digester in the mass ratio 1:5, bark / wood: water, respectively. This ratio ensured sufficient black liquor to submerge the bark or wood chips throughout the boiling period after considering the loss of liquid phase through steam.

The temperature of the digester contents was raised from the ambient level to 121^{o}C in 15 minutes. At this temperature, the pressure in the digester was 0.1 N/mm^2. These conditions of temperature and pressure were the maximum values attainable with this digester. The cooking was done at this temperature and pressure for one hour. In an industrial environment, cooking temperature for hardwoods is about 155^{o}C and 170^{o}C - 180^{o}C for softwoods. The temperatures are supposed to be built up from the ambient level in 90^{o}C. The cooking at the pick temperature is carried out for a period of 1- 2 hours (Lundquist & Kirk, 1980).

After the cooking, the liquid phase of the digester contents (black liquor) had turned brown. The intensity of the colour had the ascending order of cypress (translucent brown), pine, and eucalyptus (opaque brown). For each plant, the colour intensity of the bark extract was greater than that of the wood extract. The liquid phase was separated from the solids by use of a cloth filter.

Without further treatment, each extract was used as a concrete admixture, at varying dosage levels. The dosages were expressed as mass percentages of the cement content. For the bark extracts, the dosages were 10%, 20%, 30%, 40%, and 47.5%. For the wood extracts, the dosages used were 10%, 20% and 40%. In this exercise, the work involving bark extracts was carried out first. This gave the probable level of the optimum dosage so that it became unnecessary to cast concrete with the wood extract dosage of 47.5%. In each case, the mass of the mixing water was reduced by a mass equal to the mass of the dosage used during concrete casting. It is important to note that these plant extract admixtures are inexpensive, sustainable, and harmless to the environment.

3.1.1 Line diagram of the scheme of work

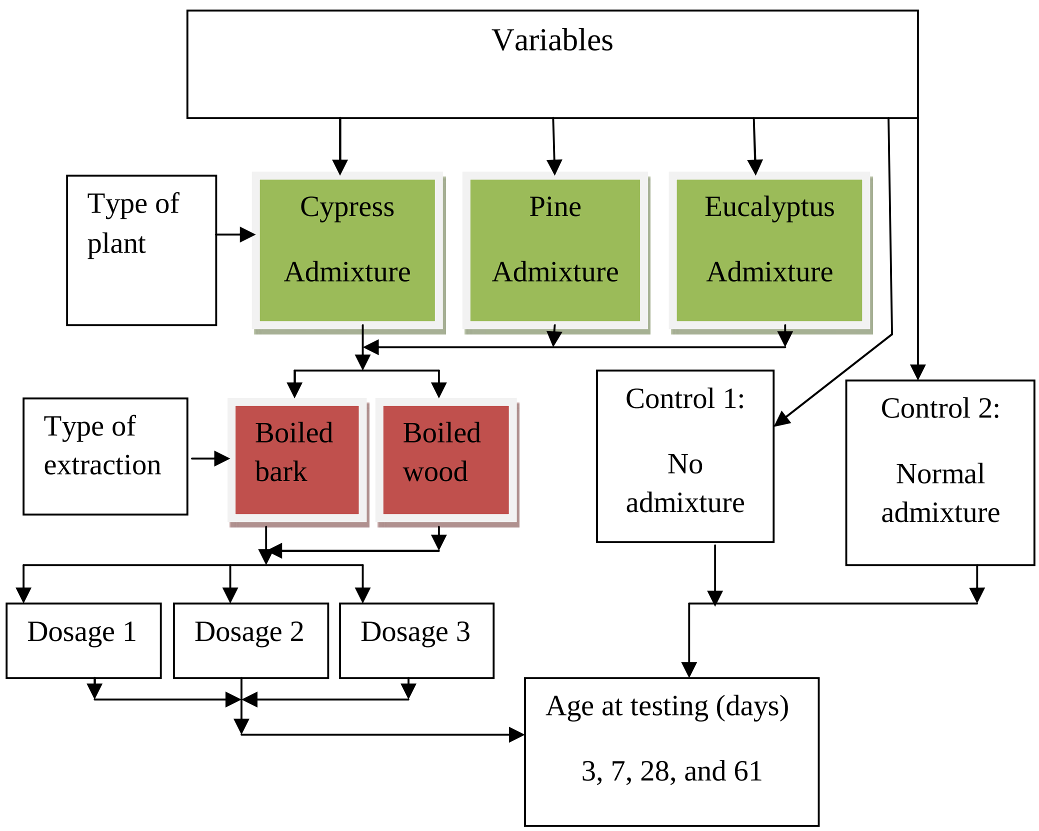


Figure 3.1: Scheme of work

3.1.2 Plant bark extract preparation

About 10.0 kg of bark were harvested from a green plant of each type; Cypress, Pine, and Eucalyptus. The bark was then cut into pieces of convenient sizes of approximate dimensions 100 mm x 20 mm and soaked in tap water for three days. For each plant type, the bark material and the soaking water were put into a digester in the mass ratio 1: 5, bark: soaking water, respectively.

3.1.3 Plant wood extract preparation

Waste wood pieces were purchased from timber merchants. The wood was then cut into pieces of convenient size: 50 mm x 20 mm x 10 mm thick. A mixture of the wood chips and tap water were put into a digester in the mass ratio 1: 5, wood chips: tap water.

3.2 Production of concrete mixes

Concrete mixes are either prescribed (specified by mix proportions) or designed (specified by characteristic strength). For example, grade C30P denotes a prescribed mix which would normally give strength of 30 N/mm^2, and grade C30 denotes a designed mix for which strength of 30 N/mm^2 would be guaranteed (Martin, Croxton & Purkiss, 1989). For this research work, mixes were designed in accordance with (BRE, 1997) procedure.

3.2.1 The design of normal concrete mix

The characteristic strength of the mix was taken as 20 N/mm^2. This value is typical in many practical cases of reinforced concrete design for structural elements such as columns, beams, and suspended floor slabs. The percentage of defectives, allowed by BS 8110 is 5%. This value was adopted.

3.2.1.1 Aggregates

The coarse aggregates used were crushed rock: a mixture of single sizes 10 mm and 20 mm in the proportions 1: 2, respectively (BRE, 1997). For the purposes of design of mixes, the water absorptions of both the fine and coarse aggregates were also determined. The fine aggregate used was river sand. Sieve analysis test was carried out to determine the percentage of the fine aggregates passing 0.6 mm sieve as is required by BRE in the mix design process.

(a) Fine aggregates (size: 5 mm – 0.075 mm)

(i) Determination of water absorption

Water of absorption for aggregates was determined in accordance with American standard for testing and materials (Murdock & Brook, 1979). Samples of natural river sand, sieved through 5.0 mm sieve and retained on 0.075 mm sieve weighing about 500 g were washed clean over a 0.075 mm sieve and then soaked in water for 24 hrs. The wet sand was separated from water by decanting over 0.075 mm sieve. The wet sand is placed on non absorbent surface and surface moisture allowed to dry out, avoiding direct sun. When the SSD state is reached the sand undergoes a colour change. The sand is then filled into an inverted flow test cone in three layers. Each layer is compacted by giving it 25 blows using the standard tamper. The tamper is raised about 5 mm above the surface of the sand and then allowed a free fall onto the sand, to constitute a single blow. After the third layer, the top of the truncated cone is leveled off and the sand around the base removed. The cone is then lifted, vertically, off the sand. Shearing of the sand cone indicates that the sand is at the SSD state. None shearing indicates that the sand is still wet and needs more time to dry out. Collapse of the cone indicates dry sand and the test should be repeated. Moisture content of sand from the sheared cone is the water absorption of the fine aggregates.

Calculations:

Mass (A) of a sample of the sand at SSD state was taken. The sand sample was then dried in an oven at 110^{o}C, for 24 hours, and mass (D) taken. Results obtained were given in Table D1 of Appendix D.

(ii) Determination of the grading of the fine aggregates

For the purposes of normal concrete mix design, in accordance with BRE method, fine aggregates are graded on the basis of the percentage of the mass passing the 0.600 mm sieve. The sieve analysis tests were conducted on three representative samples of sand. Results are given in Table D2 of Appendix D.

(b) Coarse aggregates

The coarse aggregates content was constituted from single sized 10 mm and 20 mm materials in the ratio 1: 2, 10 mm: 20 mm, respectively. For water absorption determination materials from the stock pile passing through 9.52 mm and retained on 4.76 mm sieves was used for the 10 mm single size aggregates, and that passing 20 mm sieve but retained on 9.52 mm sieve for the 20 mm single size. The samples were washed clean and soaked in water for 24 hours. The aggregates were separated from the water by decanting. Surface moisture on the particles was wiped out using an absorbent dry cloth and then transferred onto a second absorbent dry cloth. The particles were then allowed time for the moisture to dry out away from direct sun. The particles will undergo a colour change when they attain saturated surface dry (SSD) condition. In this state the sample mass A is taken. The wet aggregates were then dried in an oven at 110^{o}C for 24 hours and then the mass of oven dried aggregates D was taken. The results are given in Table D3 of Appendix D.

3.2.1.2 Cement

The Portland cement is produced in the strength classes 42.5 and 52.5 (BRE, 1997). The cement strength class 42.5 was used on account of ease of its availability in the Kenyan market. Too high cement content increases the risk of concrete cracking due to drying shrinkage in thin sections or thermal stresses in thicker sections. For these reasons a maximum cement content of 550 kg/m^3 is recommended (Kong & Evans, 1985). This value was adopted in this study. For durability, moderate conditions of exposure were assumed. The maximum coarse aggregate particle was 20 mm and therefore the minimum cement content adopted was 300 kg/m^3 (Murdock & Brook, 1979).

3.2.1.3 Workability of the mix

Slump test was used to assess the workability of the concrete. The level of workability selected for design calculations, was 30 – 60 mm. During casting, the workability was further restricted to 45 mm slump with a tolerance of 5 mm.

3.2.1.4 Mix design summary

Results of mix design calculations carried out in Appendix E are summarized in Table 3.1.

Table 3.1: Mix design materials summary (control concrete)

Quantities	Cement (kg)	Water (kg)	Fine aggregates (kg)	Coarse aggregates (kg)		
				10mm	20 mm	40mm
Per m^3	400	242.1886	670	400	800	-
Per trial mix of ----- m^3						-

(BRE, 1997)

During casting, allowance for waste of materials was taken as 15%.

3.2.2 The test concrete mixes

Each of the test mixes had the same material quantities as the control mix except for water which was partially substituted with the admixture: plant extract or the commercially available plasticizer (Sika plastiment BV40 - water reducing and retarding concrete admixture). Dosages of the plant extract used, expressed as a mass percentage of the cement content were

10%, 20%, 30%, 40%, and 47.5% for bark extracts and 10%, 20% and 40% for the wood extracts. In every case, the mixing water was reduced by an amount equal to the mass of the dosage. Before adding cement and admixture (plant extract or BV40) into the mix, the weighed aggregates were mixed with part of the mixing water and 5 minutes allowed to elapse before proceeding with the mixing operation. This advance fraction of the mixing water was at least the amount required to bring the aggregates to SSD condition. This procedure had the effect of minimizing the amount of plant extract getting into the pores of the aggregates and thus optimized its effects on strength and workability.

3.2.3 Type of specimens

The maximum coarse aggregate particle size was 20 mm. Therefore, casting was done in 100 mm cube moulds. Cylinder moulds' measurements were 100 mm diameter x 200 mm height while the beam sizes were 100 mm x 100 mm x 500 mm long (BS1881: Part 3). Demoulding of the samples was done 24 hours after casting, followed by water bath curing till testing age.

3.3 Testing of hardened concrete specimens for strength

The loading rate for all specimens was 0.2 N/ mm^2 (per second) and the stress values were reported to the nearest 0.5 N/mm^2.Compressive strength was obtained by testing the 100 mm cubes. Cylinder splitting tensile strength, f_t, was taken as:

$$f_t = \frac{2F}{\pi d l} \qquad (3.1)$$

Where F is the maximum applied force (N), d is the cylinder diameter (mm) and l is the cylinder length (mm)

Concrete strength in flexure (modulus of rupture) was determined by loading beams to failure. Symmetrical two-point loading method was used. The modulus of rupture, f, was calculated from:

$$f = \frac{M}{Z} \qquad (3.2)$$

Where M is the bending moment at failure point and Z is the elastic section modulus of the beam.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Fine aggregates (size: 5 mm – 0.075 mm)

4.1.1 Water absorption

The water absorption determination procedure was detailed in section 3.2.1.1 (a). The determined value was 0.92%. Typical values of absorption for river sand lie in the range 0.2% - 3.15% (Neville, 2011). Therefore the determined value is within the normal range.

4.1.2 Grading

Grading assessment procedure was detailed in section 3.2.1.1 (a). The determined percentage mass passing the 0.600 mm sieve was 55%. Practical values were in the range 15-100% (BRE, 1997). Hence, the value of 55% was acceptable.

4.2 Coarse aggregates

The coarse aggregates content was constituted from single sized 10 mm and 20 mm materials in the ratio 1:2, 10 mm: 20 mm, respectively as stated in methodology.

4.2.1 Water absorption

Details of procedure to determine water absorption were given in section 3.2.1.1 (b). The absorption for aggregate particles (10 mm – 5 mm) was found to be 3.79% and that for (20 mm – 10 mm) was 3.85%. Typical absorption values were in the rage 0.73-4.53% for aggregate particle size (5 – 10 mm) (Neville, 2011). The experimental value obtained was within the expected range. Typical absorption values for particle sizes (10 mm – 20 mm) were within the range 0.5-3.30% (Neville, 2011). The experimental value of 3.85% was of the same order as the typical values.

4.3 Results of tests on concrete samples

4.3.1 Plain control concrete samples

In this research, the effect of plant extracts in normal concrete is being investigated. The normal concrete was cast as a control and its properties established. The same properties were observed when the casting was done with plant extracts in the concrete mix.

Table 4.1: Results of tests on plain concrete control samples

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c ratio	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	173.646	17.5	18.0	0.6055	45	45 ± 5
		174.346	17.5				
		186.665	18.5				
7	10000	313.718	31.5	31.0			
		317.091	31.5				
		292.800	29.5				
28	10000	410.912	41.0	41.0			
		395.788	39.5				
		432.312	43.0				
61	10000	507.689	51.0	48.0			
		444.933	44.5				
		485.407	48.5				

The control concrete had been designed for a target mean strength of 33 N/mm^2 at 28 days. From results presented in Table 4.1, this strength was attained.

4.3.2 Concrete samples containing Sika plastiment BV40

Results of tests of concrete samples containing Sika plastiment BV40 (water reducing and retarding concrete admixture) are given in Table 4.2. The manufacturer recommended dosage was 0.2 – 0.5%, by weight, of the cement content.

Table 4.2: Concrete containing Sika plastiment BV40 (dosage 0.35 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Actual slump	
			Sample stress	Mean stress		Actual	Target
3	10000	180.313	18.0	18.5	0.5742	40	45 ± 5
		182.667	18.5				
		195.526	19.5				
7	10000	257.274	25.5	25.5			
		266.211	26.5				
		244.162	24.5				
28	10000	245.247	24.5	33.0			
		389.920	39.0				
		361.448	36.0				
61	10000	449.517	45.0	40.5			
		405.727	40.5				
		366.543	36.5				

Although the 28 days, target mean strength of 33 N/mm^2 is met, it is however, lower than the strength attained in control concrete.

The graphical presentation of the results in Tables 4.1 and 4.2 is given in Figure 4.1.

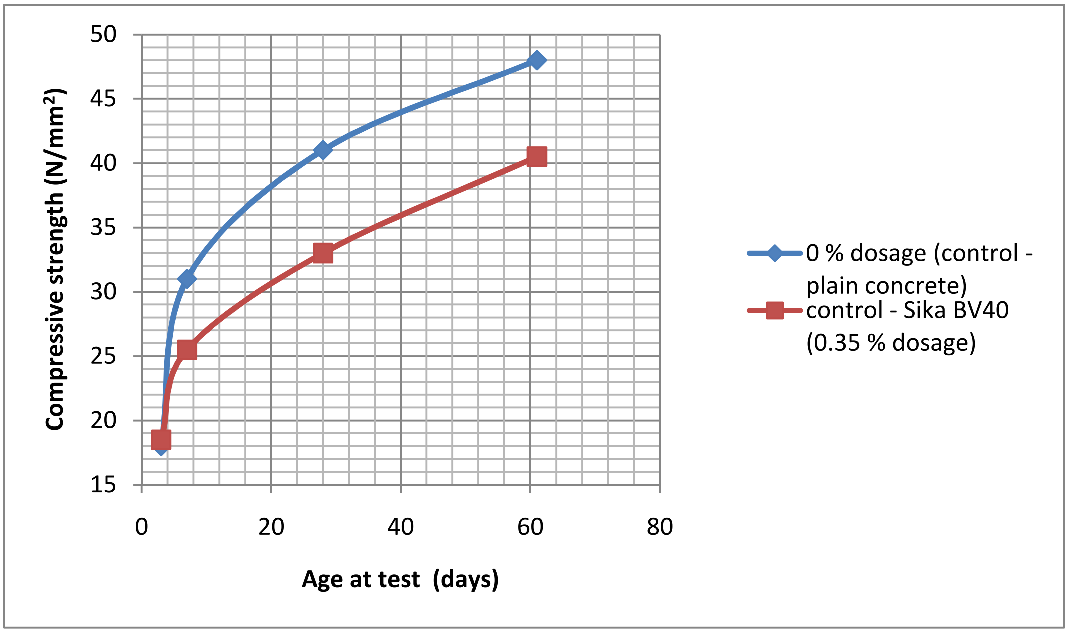


Figure 4.1: Compressive strength versus curing time

From Tables 4.1 and 4.2 and Figure 4.1, the plasticizing admixture; Sika plastiment BV40 was found to reduce the compressive strength of concrete at the ages of 7, 28, and 61 days. Sika plastiment BV40 is water reducing and retarding concrete admixture. Its observed effect on the workability of the concrete was as shown in Table 4.3. The use of this admixture improved the workability of the concrete by a scale factor of about 3.0.

Table 4.3: Effect of Sika plastiment BV40 on workability of concrete

Admixture and dosage as a fraction of cement content	w/c ratio	Workability (slump in mm)
Control concrete (0.0 % admixture)	0.6055	45
Concrete containing Sika plastiment BV40 (0.35 %)	0.6055	130

4.3.3 Concrete containing Cypress tree extracts as admixtures

4.3.3.1 Cypress bark extract tests

These tests were compressive strength, indirect tension (cylinder splitting tests), flexural strength and workability.

(i) Compressive strength tests (constant workability)

The results of these tests are given in Tables F1 to F5 of appendix F and summarized in Table 4.4. Graphical presentation of results in Table 4.4 was presented in Figure 4.2.

Table 4.4: Average stress values at different ages and the relevant slump values

Cypress bark extract as a mass percentage of the cement used	Mean compressive stress (N/mm^2)				Slump (mm)	
	3 days	7 days	28 days	61 days	Actual	Target
0.0	18.0	31.0	41.0	48.0	45	45 ± 5
10.0	6.0	13.5	21.5	29.0	45	
20.0	8.0	17.0	32.5	38.5	50	
30.0	22.5	25.5	36.5	43.5	50	
40.0	29.5	32.0	45.0	52.0	45	
47.5	22.5	29.0	34.5	35.5	45	

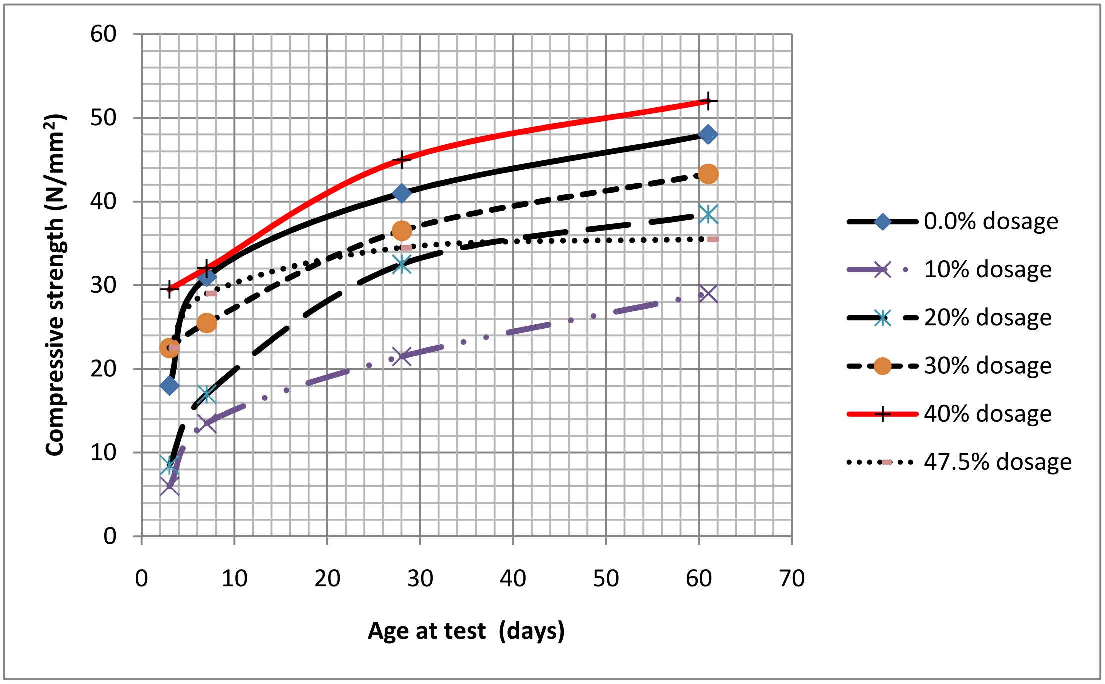


Figure 4.2: Strength versus age (concrete with varying dosages of Cypress bark extract)

From Table 4.4, and Figure 4.2, the Cypress bark extract, at a dosage of 40%, was found to increase the compressive strength of concrete. The strength gains were 63.9% at 3 days, 3.2% at 7 days, 9.8% at 28 days, and 8.3% at 61 days. At the other dosages of 10%, 20%, 30%, and 47.5% a general reduction in compressive strength was observed. At the optimum dosage of 40%, a maximum number of cement particles have each, been coated by a lignin radical. Therefore maximum number of cement particles have been dispersed resulting in increased strength. Hemicelluloses and lignin are compounds in plant extract. Hemicelluloses have the effect of retarding strength while lignin has the effect of increasing it (Kare, 2004). Effect from lignin is achieved by dispersal of cement particles. At optimum dosage, most of the cement particles have been dispersed. Since there are no more cement particles to disperse, using a dosage higher than the optimum, simply increases the hemicelluloses content with the subsequent reduction in strength. Further research is required to establish the reason why dosages below the optimum result in reduced compressive strength.

(ii) Compressive strength tests (28 days) (constant free-water/cement ratio)

The variation of the 28 day compressive strength with the cypress extract dosage was also investigated. The concrete was cast at a constant w/c ratio of 0.6055. The results were reported in Table 4.5 and graphically presented as a scatter diagram in Figure 4.3. Visual inspection of the diagram indicates a linear relationship between the two variables. From Table F6 and equation F1 of appendix F, correlation coefficient r was calculated and found to be 0.178. Since 0.178 > 0, then, there exists a linear relationship between the stress y and the dosage x. This relationship is given by the equation

$$y = a + bx \qquad (4.1)$$

Numerical values of the constants a and b of equation (4.1) were calculated from Table F6 and equations (F2.1) and (F2.2) of Appendix F and found to be 38.93 and 0.0198, respectively.

Table 4.5: Stress values with different dosages (w/c ratio constant)

Cypress bark extract as a mass percentage of the cement used	w/c ratio	Area (mm^2)	Load (kN)	The 28 days compressive strength (N/mm^2)	
				Sample strength	Mean strength
0	0.6055	10000	410.912	41.091	41.0
			395.788	39.579	
			432.312	43.231	
10	0.6055	10000	375.615	37.562	35.5
			353.171	35.317	
			333.745	33.375	
20	0.6055	10000	337.322	33.732	40.5
			446.799	44.680	
			435.974	43.597	
30	0.6055	10000	377.579	37.758	39.5
			402.900	40.290	
			410.219	41.022	
40	0.6055	10000	401.149	40.115	40.5
			385.063	38.506	
			428.718	42.872	
47.5	0.6055	10000	402.299	40.230	39.5
			406.384	40.638	
			372.709	37.271	

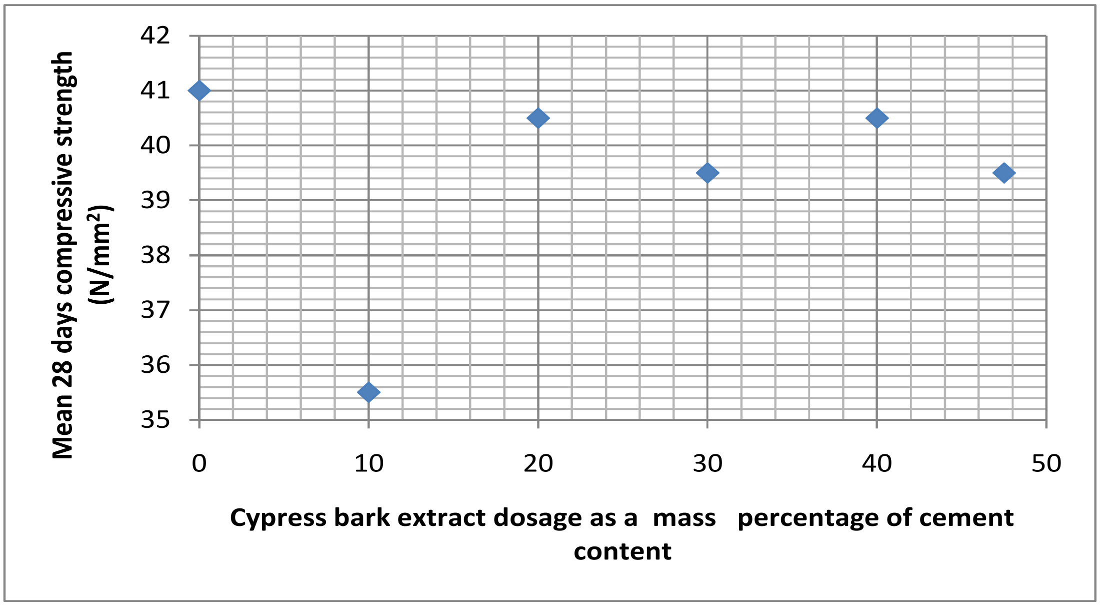


Figure 4.3: Scatter Diagram (Cypress)

(iii) Indirect tensile strength (cylinder splitting) tests

From Figure 4.2, the optimum dosage was found to be 40%. The extract effect on concrete tensile strength was investigated at this dosage level. Results were reported in Table 4.7.

Table 4.7: The 28 days cylinder splitting strength (indirect tension)

Cypress bark extract dosage	w/c ratio	Cylinder sample mass (g)	Load (kN)	The 28 days cylinder splitting strength (N/mm^2)	
				Sample stress	Mean stress
0.0%	0.605	3814.0	117.	3.731	3.5
		3691.8	112.	3.567	
		3715.4	119.	3.814	
40%	0.605	3850.0	86.5	2.756	3.0
		3782.0	89.5	2.850	
		3741.5	87.3	2.782	

From Table 4.5, the 28 days compressive strengths of control concrete and concrete containing 40% cypress bark extract admixture were 41 N/mm^2 and 40.5 N/mm^2, respectively. For the control concrete, splitting strength of 3.5 N/mm^2 is 8.5% of its compressive strength. For the concrete containing admixture 3.0 N/mm^2 is 7.4% of its compressive strength. The cylinder splitting strength of concrete is 8.3% to 12.5% of its compressive strength (Kong & Evans, 1985). Therefore the use of the admixture resulted in reduced tension strength of the concrete.

(iv) Flexural strength tests

Just as in the case of testing for tensile strength, the effect of extract on flexural strength was investigated at the optimum dosage of 40%. Two points beam loading tests were done on beam samples at the age of 28 days. Results are given in Table 4.8.

Table 4.8: The 28 days flexural strength

Cypress extract dosage	w/c ratio	Sample Mass (g)	Crack eccentricity (mm)	Load (kN)	Flexural strength (N/mm^2)	
					Sample stress	Mean stress
0.0%	0.61	11657.4	20.0	10.660	5.595	5.5
		11789.5	10.0	10.403	5.462	
		11457.3	30.0	11.025	5.788	
40%	0.61	11954.5	40.0	8.288	3.730	4.5
		11926.0	0.0	10.527	4.737	
		12155.5	10.0	10.938	4.922	

Comparing results in Tables 4.7 and 4.8: For control concrete, mean flexural stress is 157% of the mean tension stress and 150% for the concrete containing 40% admixture.

The flexural strength of concrete (modulus of rupture) is about 150% of its cylinder splitting strength (Kong & Evans, 1985). Therefore, this relationship between the two types of stresses is unaffected by the use of the admixture.

(v) Workability tests

To investigate the effect of the cypress extract admixture on the workability, mixes were cast at a constant w/c ratio of 0.6055 as the dosages were varied. The slump test results were reported in Table F7 of appendix F, and graphically presented in Figure 4.4. The workability of the fresh concrete mix was observed to increase with increasing dosages of the cypress bark extract until a critical dosage was reached. Dosages higher than the critical value did not result in higher workability. From Figure 4.4, the critical dosage is 20%, giving a workability of about 135 mm slump. This raised the workability of the control concrete (45 mm slump) by a scale factor of 3.0.

From Figure 4.2, the optimum dosage for strength improvement was found to be 40% which differs from the critical dosage of 20% for workability enhancement. The two values were expected to be the same. Further research is required to explain this behavior.

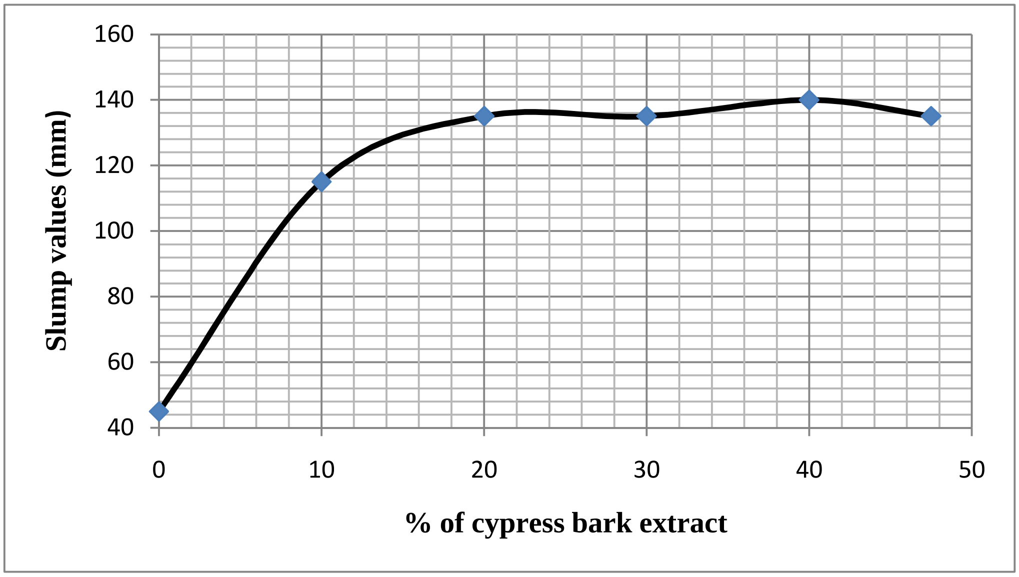


Figure 4.4: Slump versus % of cypress bark extract

4.3.3.2 Cypress wood extract

These tests were compressive strength and workability. Casting of concrete containing wood extracts was done after tests containing bark extracts had been finalized. Optimum dosages in cypress, pine and eucalyptus were 40%, 20% and 10%, respectively. Optimum dosages for concrete containing wood extracts were expected to fall within the same range of 10% to 40%. Casting was therefore done for extract contents of 10%, 20%, and 40%.

(i) Compressive strength tests

Results of tests involving this extract were given in appendix F: Tables F8, F9 and F10 and their summary in Table F11. Graphical presentation was given in Figures 4.5.

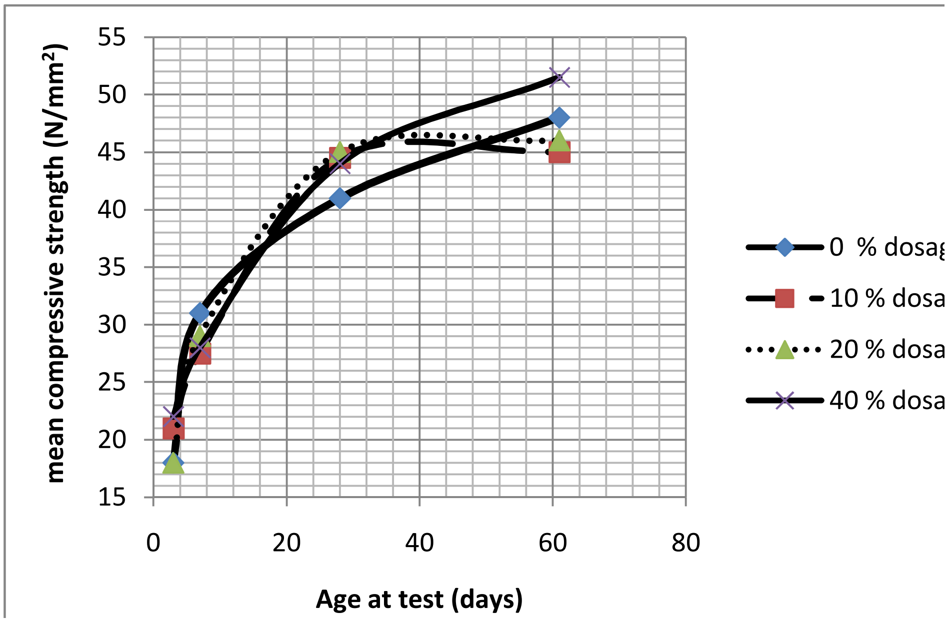


Figure 4.5: Strength versus age (concrete with varying dosages of Cypress wood extract)

From Figure 4.5, all dosages of the extract resulted in some improvement of the compressive strength; the maximum being attained at a dosage of 40%. Strength increases were 22 %, 10 %, 7 %, and 7 % at 3 days, 28 days, and 61 days respectively. This conforms to the existing theory of lignin based admixtures that presence of lignin should result in increased strength.

From table F11, a reduction in the water content required to achieve the target workability was observed. The relationship between the water reduction and the dosage was presented in Figure 4.6.

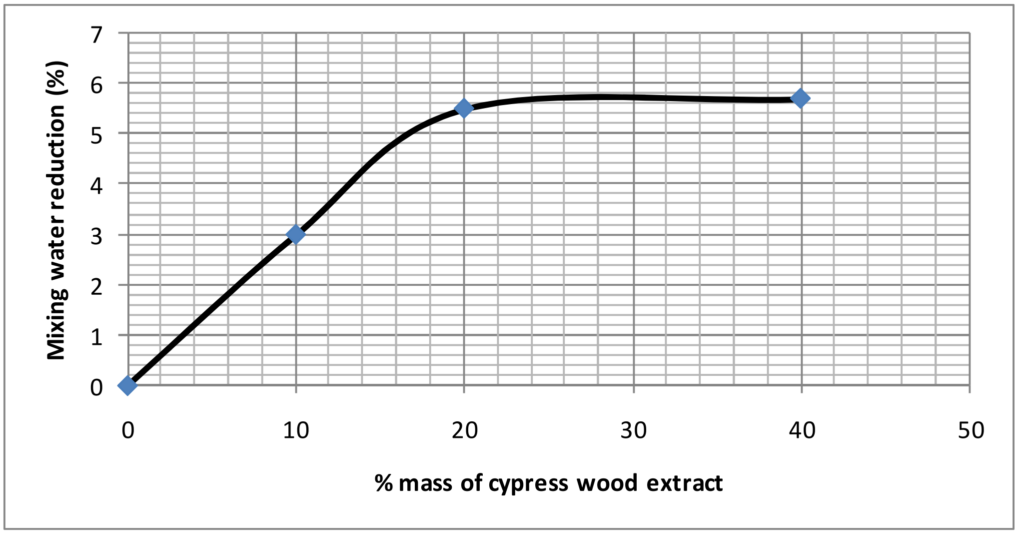


Figure 4.6: Mixing water reduction versus %mass of cypress wood extract

Water reduction increased with the dosage with a maximum of 6% being attained at a dosage of 25%. Water reduction expected to result from using a lignin based admixture is in the range 5-10% (Schultz, 1980).

(ii) Effect of the cypress wood extract on the workability

Casting was done with a constant free-water /cement ratio and the resulting workability reported in Table F13 of appendix F. Graphical presentation of the results was done in Figure 4.7. From the figure, the maximum workability attained from the use of the extract was 160 mm; at a dosage of 15%. The workability for the control concrete was 45 mm. Therefore, an improvement of 115 mm had been attained. The expected improvement was in the range 30 mm to 150 mm (Shetty, 2009).

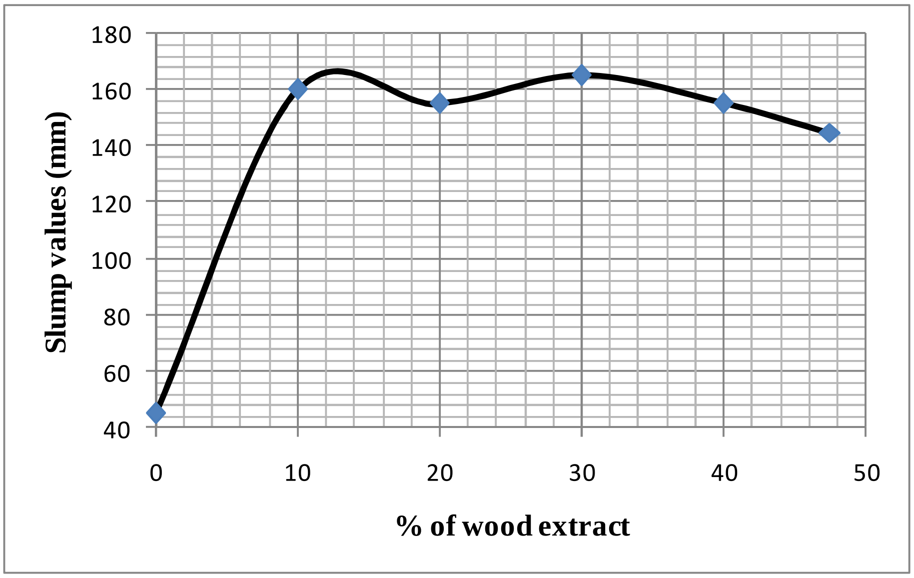


Figure 4.7: Slump values versus % mass of cypress wood extract

4.3.3.3 Comparison of properties of concrete made with cypress extracts

Table 4.9: Properties of concrete made with cypress tree extracts as admixtures

Concrete property			Cypress Bark	Cypress Wood
Compressive strength	Optimum dosage for strength gain		40 %	40 %
	Percentage strength gain at age (days)	3	63.9	22.2
		7	3.2	-9.7
		28	9.8	7.3
		61	8.3	7.3
Concrete mixing water percentage reduction to attain a slump of 45 $\pm$ 5 mm		At dosage 10 %	None	3.0
		At dosage 20 %	None	5.5
		At dosage 40 %	None	5.7
Workability		Scale factor	3.0	3.5
		Critical dosage	20 %	10

(i) Compressive strength

From Table 4.9, for both bark and wood extracts, the optimum dosage was 40%. For both extracts, gain in strength using the 40% dosage was a maximum at 3 days curing period and a minimum at 7 days. At this age of 7 days, for the wood extract, the strength was 10% lower than that of control concrete. At the design age of 28 days the strength gain was, in both cases, about 10%.

(i) Mixing water reduction

From Table 4.9, use of bark extract did not result in any reduction of mixing water while use of the wood extract resulted in water reduction within the expected range. This would imply that the source of lignin based admixtures in the market is wood.

(ii) Workability

For both extracts, the scale factor is within the normal range. However, wood extract is more effective in improving the workability.

4.3.4 Concrete samples containing Pine tree extracts as admixtures

4.3.4.1 Pine bark extract

These tests were compressive strength, indirect tension (cylinder splitting tests), flexural strength and workability.

(i) Compressive strength tests (constant workability)

The results were reported in Appendix G: Tables G1 to G5 and summarized in Table G6. Graphical presentation was given in Figure 4.8.

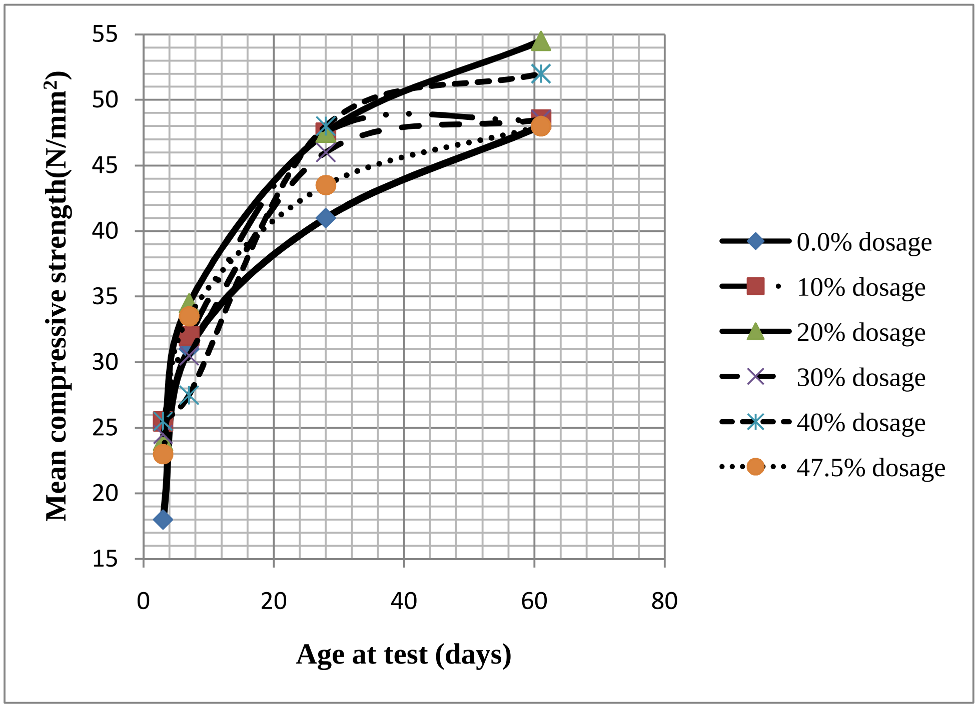


Figure 4.8: Strength versus age (concrete containing Pine bark extract)

From Table G6 and Figure 4.8, each dosage resulted in some strength gain; with the maximum being realized at a dosage of 20% (optimum dosage) at which strength improvements were 22.2%, 11.3%, 15.9%, and 13.5% at the ages of 3, 7, 28, and 61 days, respectively. It is possible to attain a strength gain, at 28 days, of 25%, with lignin based admixtures in the same class (Schutz, 1980). The low value of 15.9%, realized in this project can be attributed to the presence of hemicelluloses in the extract. Further study is required to devise a technique to remove hemicelluloses from the extract.

(ii) Compressive strength tests (28 days) (constant free-water/cement ratio)

Results of investigation of the variation of the 28 day compressive strength with the pine extract dosage was reported in Appendix G: Table G7. Results' scatter pattern was presented in Figure 4.9.

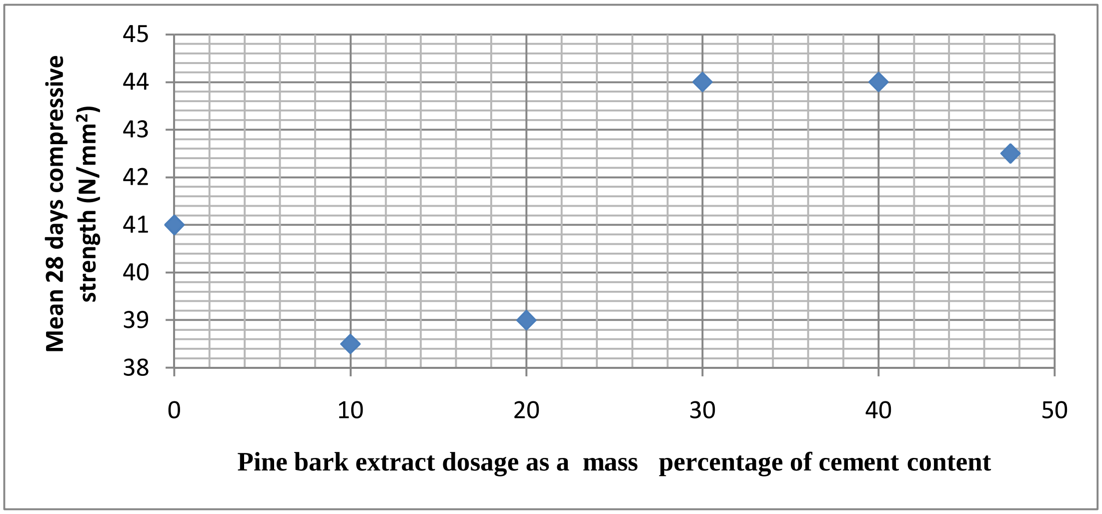


Figure 4.9: Scatter Diagram (Pine)

Visual inspection of Figure 4.9 indicates a linear relationship between strength and dosage. Statistical analysis of data in Table G7 using equations (F1) and (F2) gave correlation coefficient r as 0.66 and the stress predictor equation

$$Stress\ y = 0.087x + 39.35 \qquad (4.2)$$

Where x was the pine bark extract dosage.

(iii)Indirect tensile strength (cylinder splitting) tests

The extract effect on concrete tension strength was investigated at a dosage of 40%. Results are given in Table 4.10.

Table 4.10: The cylinder splitting strength of pine bark extract concrete

Pine extract dosage	w/c ratio	Cylinder sample mass (g)	Load (kN)	The 28 days	
				Sample strength	Mean strength
0.0 %	0.6055	3814.0	117.213	3.731	3.5
		3691.8	112.045	3.567	
		3715.4	119.816	3.814	
40 %	0.6055	3713.5	90.822	2.891	3.0
		3746.5	88.631	2.821	
		3730.5	88.297	2.811	

The cylinder splitting strength of concrete is 8.3 % to 12.5 % of its compressive strength (Kong & Evans, 1985). From Table G7, the 28 days compressive strength of this concrete is 44.0 N/mm^2 whose 8.3 % is 3.5 N/ mm^2 > 3.0 N/mm^2 of Table G7. Therefore, use of the admixture had not improved the tensile strength of concrete, even though, it had been anticipated.

(iv) Flexural strength tests

Two points beam loading tests were done. Results were reported in Table 4.11.

Table 4.11: The 28 days flexural strength of concrete (w/c ratio of 0.6055)

Pine bark extract dosage	Sample mass (g)	Crack eccentricity (mm)	Load (kN)	Flexural strength (N/mm^2)	
				Sample stress	Mean stress
0.0 %	11657.4	20.0	10.66	5.595	5.5
	11789.5	10.0	10.40	5.462	
	11457.3	30.0	11.02	5.788	
40 %	12191.5	75	9.761	4.393	4.5
	12471.0	35	9.095	4.093	
	11981.5	40	9.944	4.475	

Comparing results of Tables 4.10 and 4.11: For control concrete, mean flexural stress is 157% of the mean tension stress and 150% for the concrete containing 40% pine bark admixture. The flexural strength of concrete (modulus of rupture) is about 150% of its cylinder splitting strength (Kong & Evans, 1985). Therefore, this relationship is maintained in the test concrete but use of the admixture had not improved the flexural strength, against expectation.

(v) Effect of pine bark extract on the workability of the concrete

For this investigation resulting slump test values were recorded in appendix G: Table G8. Graphical presentation was made in Figure 4.10.

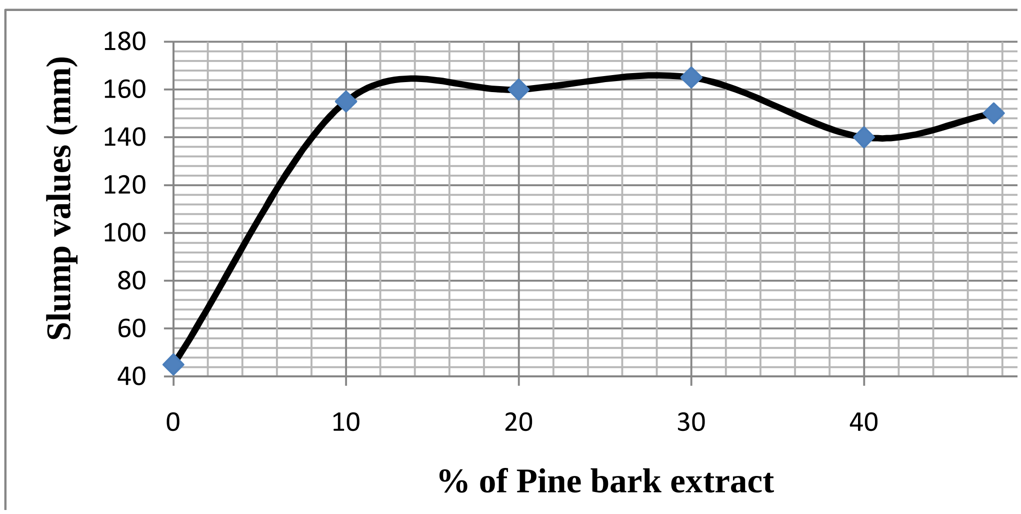


Figure 4.10: Slump values versus % mass of Pine bark extract

Working mechanism of lignin based admixtures is discussed in section 2.2.1. From Figure 4.10 the workability of the mix increased with the increase of the dosage. The maximum slump of about 160 mm was attained at a dosage of 15% (critical dosage).

4.3.4.2 Pine wood extract

(i) Compressive strength tests

Results of tests involving this extract were given in Appendix G: Tables G9, G10 and G11. Summary of these results was given in Table G12. Graphical presentation of the results was given in Figure 4.11.

From Table G12 and Figure 4.11, the 20% is the optimum dosage for pine tree wood extract. At this dosage, strength increases were 11.1%, 11.0%, and 5.2% at 3 days, 28 days, and 61 days respectively. At the age of 7 days, the admixture suppressed strength by 8.1%. The theory of working mechanism of lignin based admixtures is presented in section 2.2.1.

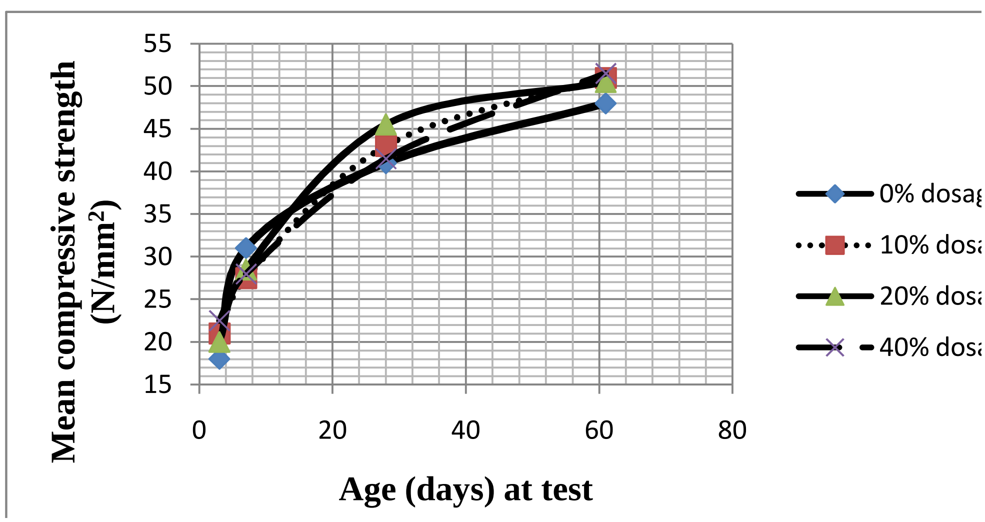


Figure 4.11: Strength versus age (concrete with varying dosages of Pine wood extract)

(ii) Mixing water reduction

As recorded in Table G12, use of this admixture resulted in reduction of mixing water required to achieve the target workability. Graphical variation of this reduction water with the dosage was presented in Figure 4.12.

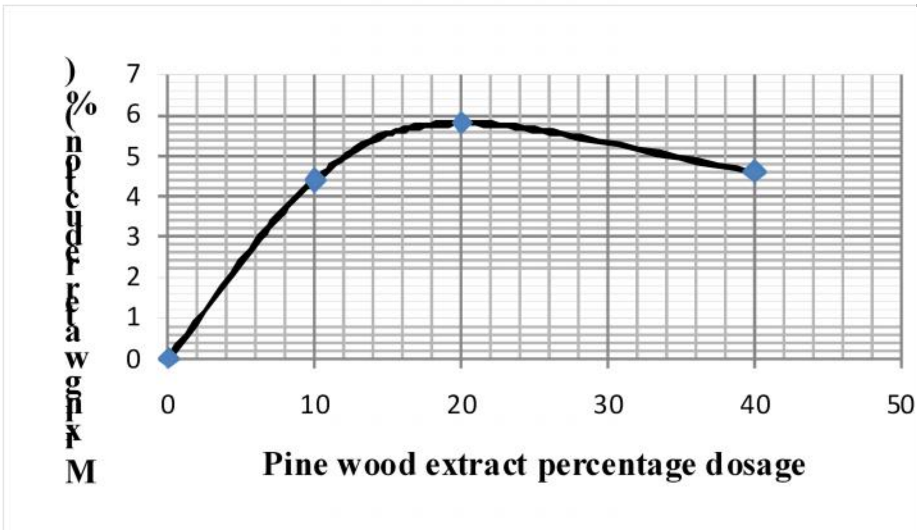


Figure 4.12: mixing water reduction versus % mass of Pine wood extract

From Figure 4.12, water reduction increased with the dosage. The maximum water reduction of about 6% was attained at a dosage of 20%. Water reduction expected to result from using a lignin based admixture is in the range 5-10% (Schultz, 1980). Hence, this value of water reduction was within the expected range.

(iii) Workability

For this investigation, the resulting slump values were recorded in appendix G: Table G13. Graphical presentation was made in Figure 4.13.

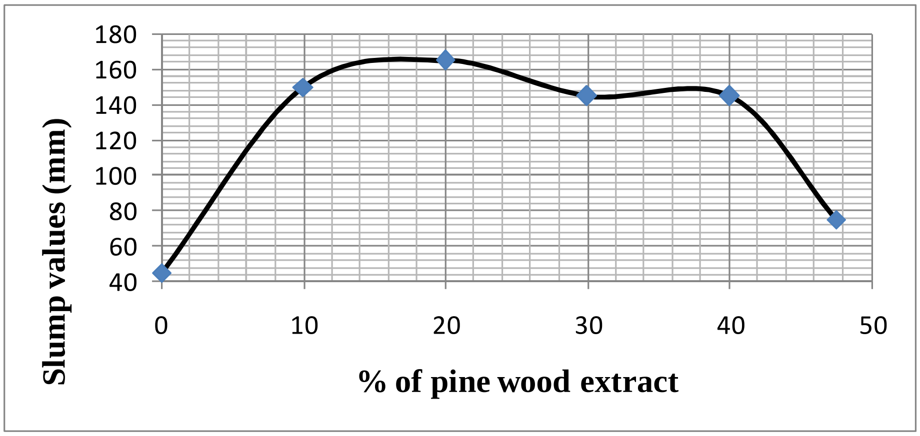


Figure 4.13: Slump versus % of Pine wood extract

From Table G13, the workability of control concrete was 45 mm slump. From Figure 4.13, workability increased with the dosage up to the critical dosage of 15%. At that dosage, a maximum workability of about 160 mm had been attained (115 mm increase over the control concrete workability). The expected increase was 30 mm to 150 mm (Shetty, 2009). Working mechanism of lignin based water reducers is discussed in section 2.2.1.

4.3.4.3 Comparison of properties of concretes made with pine extracts

The properties of concretes made with pine bark and wood extracts are summarized in Table 4.12.

(i) Compressive strength

From Table 4.12, the optimum dosage was 20% for both bark and wood extracts. Typical dosage for commercial admixtures, in the same class was 0.1% to 0.4% (Shetty, 2009). This difference in dosages is explained by the presence of hemicelluloses, in the extracts that otherwise would have been removed in the commercial grades of the admixtures.

The expected gains in strength, as a result of using this class of admixtures can be up to 25% (Schutz, 1980). From Table 4.12, the gains in strength as a result of using pine extract admixtures were higher with bark extract. At a curing age of 7 days, stress value for the concrete with wood extract was below the control concrete stress value by 8.1%. At the stress design age of 28 days, the higher stress gain was with bark extract, at a value of 15.9%. This is below the expected value of 25%. This too, can be explained by the presence of hemicelluloses, which otherwise would have been removed in commercial grade admixtures.

Table 4.12: Properties of concretes made with pine tree extracts as admixtures

Concrete property			Pine tree extract	
			Bark	Wood
Compressive strength	Optimum dosage for strength gain		20 %	20 %
	Percentage strength gain (for the 20% dosage) at age (days)	3	22.2	11.1
		7	11.3	- 8.1
		28	15.9	11.0
		61	13.5	5.2
Concrete mixing water percentage reduction to attain a slump of 45 $\pm$ 5 mm		At dosage 10 %	2.0	4.4
		At dosage 20 %	0.0	5.8
		At dosage 40 %	2.5	4.6
Workability of concrete		Scale factor	3.5	3.0
		Critical dosage	15%	15%

(ii) Mixing water reductions

From Table 4.12, higher values of mixing water reductions were achieved when wood extract was used. Water reduction expected to result from using a lignin based admixture was 5-10% (Schultz, 1980). For the bark extract, the water reduction values were below the expected values while as the values obtained with wood extracts are within the expected range. This would imply that the published information was based on the wood extracts.

(iii) Workability

The workability for the control concrete was 45 mm slump. For each of the extracts, the critical dosage was 15%. The maximum workability achieved at this critical dosage was 160 mm slump in each case (115 mm increase). The expected increase was 30 mm to 150 mm (Shetty, 2009). Hence, as regards workability, the performances of the extracts as admixtures were satisfactory.

4.3.5 Concrete samples containing Eucalyptus tree extracts as admixtures

4.3.5.1 Eucalyptus bark extract

The tests conducted were compressive strength, indirect tension (cylinder splitting tests, flexural strength and workability.

(i) Compressive strength tests (constant workability)

The results of the compressive strength tests were given in appendix H: Tables H1 to H5 and summarized in Table H6. Graphical presentation was done in Figure 4.14.

From Figure 4.14, the optimum dosage was 10%. For the optimum dosage, compressive stress increases were 19.5%, 6.0%, and 3.0% at the ages of 3, 28 and 61 days, respectively. The compressive stress, for the dosage, was below the control concrete value by 3% at the age of 7 days. The design age of concrete is 28 days. Hence, the relevant strength gain for design was 6%. The expected strength gain, at that curing age was 25% (Schutz, 1980). For this extract, at all other dosages, stresses were lower than the control concrete at the age of 28 days. Hence, the performance of this extract was not satisfactory from strength consideration.

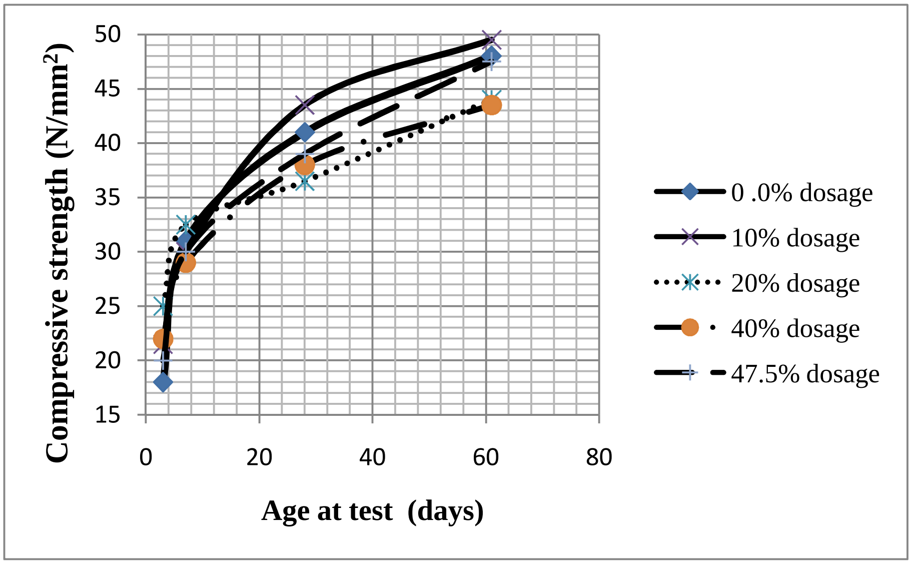


Figure 4.14: Strength versus age (concrete containing Eucalyptus bark extract)

(ii) Compressive strength tests (28 days) (constant free-water/cement ratio)

Results of these tests were reported in Appendix H: Table H7. Graphical presentation was done in Figure 4.15.

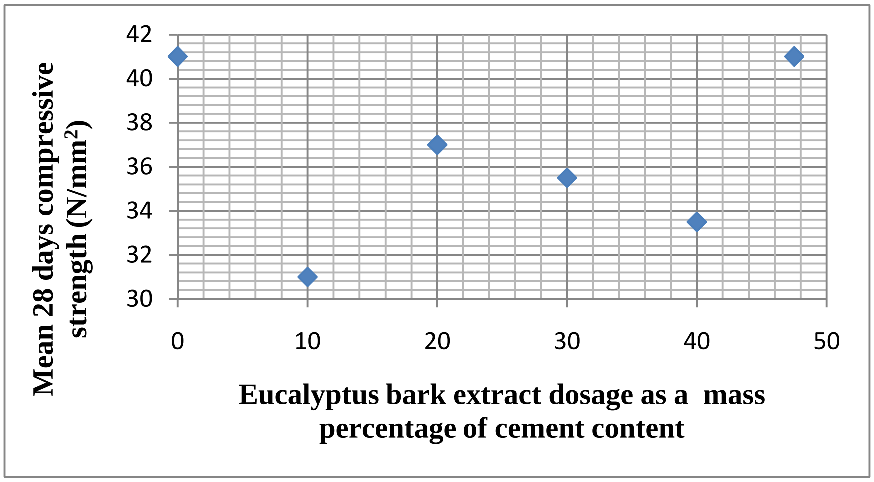


Figure 4.15: Scatter Diagram (Eucalyptus)

Visual inspection of Figure 4.15 indicates a linear relationship between strength and dosage. Statistical analysis of data in Table H7 and application of equations (F1) and (F2) gave correlation coefficient r as 0.03 and the stress predictor equation

$$Stress\ y = 0.0036x + 36.33 \qquad (4.3)$$

Where x = Eucalyptus bark extract dosage.

The gradient for the stress predictor equation was very low which can be attributed to the presence of hemicelluloses in the extract.

(iii) Indirect tensile strength (cylinder splitting) tests

This investigation was carried out at a randomly selected dosage of 30%. The cylinder splitting strength of concrete is 8.3% to 12.5% of its compressive strength (Kong & Evans, 1985). From appendix H: Table H6, the 28 days compressive strength for the control concrete was 41 N/mm^2 whose 8.3% was 3.4 N/mm^2. From Table 4.13, the experimental value of tension is within the expected range. From appendix H: Table H6, the 28 days compressive strength of concrete containing the admixture was 42 N/mm^2 whose 8.3% was 3.5 N/mm^2. The experimental value obtained was 2.5 N/mm^2. Hence the admixture was found to lower the tensile strength of concrete.

Table 4.13: The tensile strength with 30% dosage (Eucalyptus bark extract)

Eucalyptus bark extract dosage	w/c ratio	Cylinder sample mass (g)	Load (kN)	The 28 days cylinder splitting strength (N/mm^2)	
				Sample stress	Mean stress
0.0 %	0.6055	3814.0	117.213	3.731	3.5
		3691.8	112.045	3.567	
		3715.4	119.816	3.814	
30 %	0.6055	3745.5	75.009	2.388	2.5
		3794.5	87.254	2.777	
		3778.5	76.809	2.445	

(iv) Flexural strength

Two points beam loading tests were conducted at the age of 28 days. The eucalyptus bark extract dosage used was 30%, which was randomly selected. Results were recorded in Table 4.14. The flexural strength of concrete (modulus of rupture) is about 150% of its cylinder splitting strength (Kong & Evans, 985). For both control and concrete containing the admixture, flexural strength values of Table 4.14 are about 150% of the values recorded in Table 4.13. Therefore, the relationship between the two types of stress was unaffected by the use of the admixture.

Table 4.14: The flexural strength (30% dosage) of the eucalyptus bark extract (w/c: 0.61)

Eucalyptus bark extract dosage	Sample mass (g)	Crack eccentricity (mm)	Load (kN)	The 28 days flexural	
				Sample stress	Mean stress
0.0%	11657.4	20.0	10.660	5.595	5.5
	11789.5	10.0	10.403	5.462	
	11457.3	30.0	11.025	5.788	
30%	12609.0	15	8.756	3.940	4.0
	12461.5	40	8.730	3.928	
	12444.0	20	8.379	3.771	

(v) Workability

The results for this investigation were recorded in appendix H: Table H8. Graphical presentation was done in Figure 4.16.

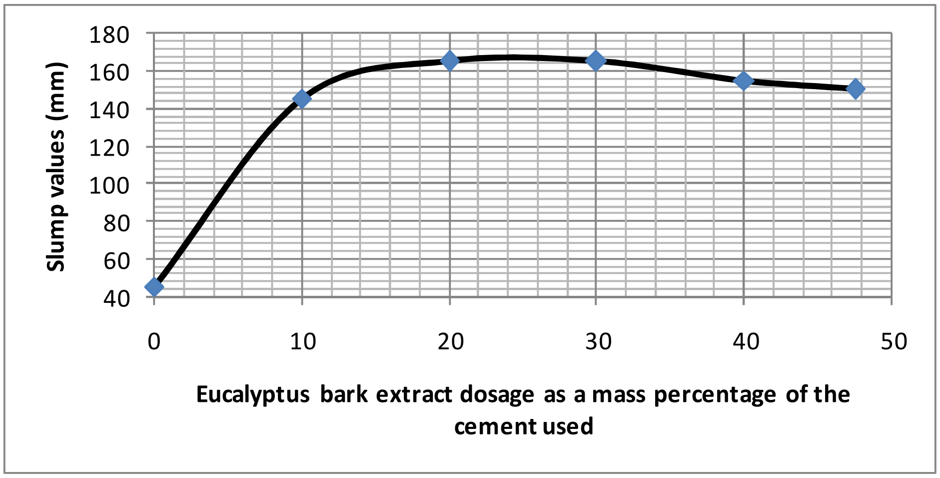


Figure 4.16: Slump versus the Eucalyptus bark extract dosage

From appendix H: Table H8, the workability of control concrete was 45 mm slump. From Figure 4.16, workability increased with the dosage of eucalyptus extract up to the critical dosage of 20%. At that dosage, a maximum workability of about 160 mm had been attained (115 mm increase over the control concrete workability). The expected increase was 30 mm to 150 mm (Shetty, 2009). From the workability consideration, the admixture's performance was satisfactory.

4.3.5.2 Eucalyptus wood extract

Tests conducted for this extract were compressive strength and workability.

(i) Compressive strength

Results of the tests were given in appendix H: Tables H11 to H13 and summarized in Table H14. Graphical presentation was done in Figure 4.17.

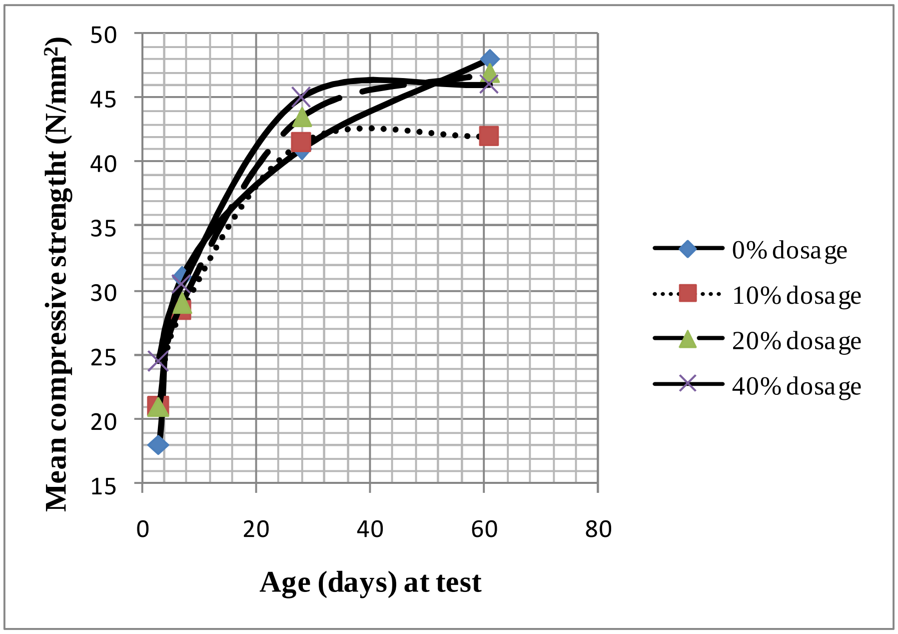


Figure 4.17: Strength versus age (concrete containing Eucalyptus wood extract)

The concrete design age is 28 days. From Figure 4.17, the strength recorded for all the dosages was higher than that of the control concrete at the age of 28 days. The highest gain in strength was obtained with a dosage of 40%. At the optimum dosage of 40%, the strength gains were 36.0%, and 10.0%, at the ages of 3, and 28 days, respectively. Strength reductions of 1.5%, and 4% were observed at the ages of 7, and 61 days, respectively. The expected strength gain, at the curing age of 28 days was 25% (Schutz, 1980). The reduced strength gain may be attributed to the presence of hemicelluloses in the extract.

(ii) Mixing water reduction

As recorded in Table H14, use of this admixture resulted in reduction of mixing water required to achieve the target workability of 45 mm slump. Graphical variation of reduction water with the dosage was presented in Figure 4.18.

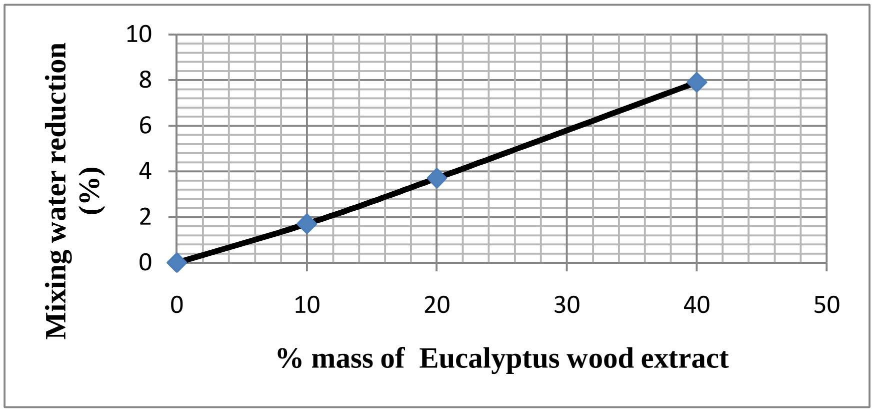


Figure 4.18: % mixing water reduction versus % mass of Eucalyptus wood extract

From Figure 4.18, water reduction increased with the dosage. Water reduction of about 8% was attained at the optimum dosage of 40%. Water reduction expected to result from using a lignin based admixture was in the range 5-10% (Schultz, 1980). Hence, this value of water reduction was within the expected range.

(iii) Workability

(iv) Experimental results obtained for these tests were recorded in appendix H: Table H15. Graphical presentation of the results was done in Figure 4.19.

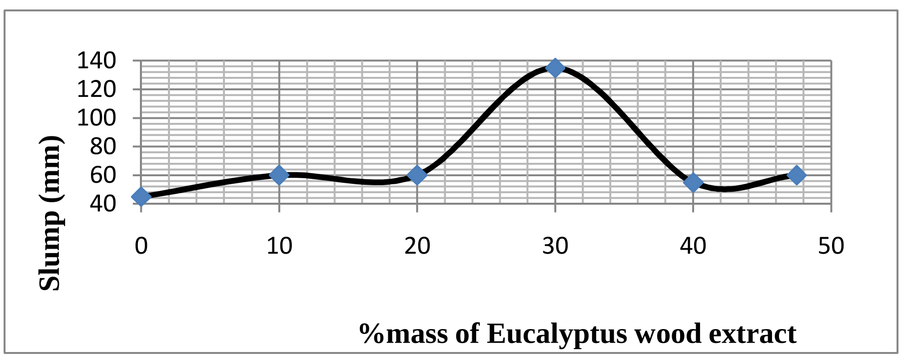


Figure 4.19: Slump values versus the Eucalyptus wood extract dosage

The workability of the control concrete was 45 mm. From Figure 4.19, workability of the mix containing the Eucalyptus wood extract increased with the dosage; reaching a maximum slump of 135 mm (90 mm increase). This was attained at a dosage of 30%. The expected increase was 30 mm to 150 mm (Shetty, 2009). From the workability consideration, the admixture's performance was as expected.

4.3.5.3 Comparison of properties of concretes made with Eucalyptus tree extracts

The properties of concretes made with eucalyptus bark and wood extracts are summarized in Table 4.15.

(i) Compressive strength

From Table 4.15, the optimum dosage was 10% for both bark and 40% for wood extracts. Typical dosage for commercial admixtures, in the same class was 0.1% to 0.4% (Shetty, 2009). This difference in dosages between the extracts and commercials admixtures may be explained by the presence of hemicelluloses, in the extracts that otherwise would have been removed from the commercial grades of the admixtures.

The expected gains in strength, as a result of using this class of admixtures can be up to 25% (Schutz, 1980). From Table 4.15, the gains in strength, at 28 days, as a result of using Eucalyptus extract admixtures were 6% and 10%, for the bark and wood extracts, respectively. Again, values lower than the expected can be attributed to the presence of hemicelluloses in the extracts. At a curing age of 7 days, stress value for the concrete with either extract was below that of the control concrete. This has no practical consequence since at that age concrete is still under temporary support.

Table 4.15: Properties of concrete made with eucalyptus tree extracts as admixtures

Concrete property			Eucalyptus tree extract	
			Bark	Wood
Compressive strength	Optimum dosage for strength gain		10%	40%
	Percentage strength gain at	3	19.5	36.0
		7	- 3	- 1.5
		28	6.0	10.0
		61	3.0	- 4.0
Concrete mixing water percentage reduction to attain a slump of 45 ± 5 mm		At dosage 10%	2.3	1.7
		At dosage 20%	0.0	3.7
		At dosage 40%	0.0	7.9
Workability of concrete		Scale factor	3.5	3.0
		Critical dosage	20%	30%

(i) Mixing water reduction

From Table 4.15, mixing water reductions were achieved when wood extract was used. The water reduction obtained with the Eucalyptus wood extract, at the optimum dosage of 40% was 7.9%. Water reduction expected to result from using a lignin based admixture was 5-10% (Schultz, 1980). Therefore, from workability consideration, the performance of the extract was satisfactory. This also would imply that the published information was based on the wood extracts.

(ii) Workability

The workability for the control concrete was 45 mm slump. For the Eucalyptus bark extract, the critical dosage of 20% produced a workability increase of 115 mm slump. The Eucalyptus wood extract critical dosage of 30% gave workability increase of 90 mm slump. The expected increase was 30 mm to 150 mm (Shetty, 2009). Therefore, as regards workability, the performance of the extracts as admixtures was satisfactory.

4.3.6 Comparison of results from the plant extracts and Sika plastiment admixtures

In sections 4.3.1 to 4.3.5, results of strength and workability tests, conducted involving a commercial admixture (BV40) and plant extracts were given. For each plant extract, the dosage that gave the best improvement of compressive strength (optimum dosage) had been determined. Similarly, the lowest plant extract dosage that gave the highest workability improvement (critical dosage) had been experimentally determined. For Cypress, Pine and Eucalyptus, these dosage values were reported in Tables 4.9, 4.12 and 4.15, respectively. The manufacturer recommended dosage for the commercial admixture Sika plastiment BV40, was 0.2% to 0.5%. A dosage of 0.35% was used.

4.3.6.1 Strength

Strength profiles over the curing period, for control concrete and concrete containing the various admixtures are shown in Figure 4.20.

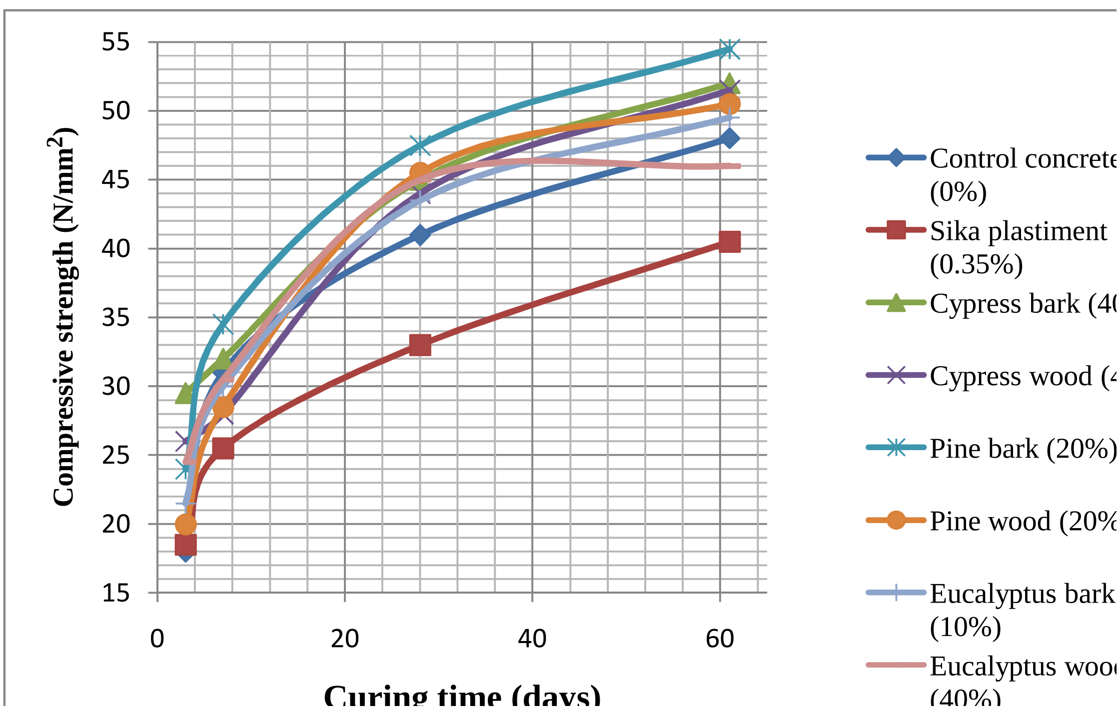


Figure 4.20: Strength versus age (optimum dosages in concrete)

(a) Sika plastiment BV40

As illustrated in Figure 4.20, for this commercially available admixture, strength values, over the entire testing period, were lower than that of the control concrete, although, an improvement of 25% had been expected.

(b) Cypress

From Table 4.9, the optimum dosages relating to bark and wood extracts were at the same level of 40%. From the plotting of the relevant strength profiles in Figure 4.20, bark extract had result in higher strength values; indicating a higher concentration of lignin. In both cases, strength of control concrete had been improved at the concrete design age of 28 days. Hence, either of the extract had better results than the purchased admixture.

(c) Pine

As in the case of Cypress, from Table 4.12, the optimum dosages for bark and wood were equal at 20%. From Figure 4.20, the strength values for bark and wood extracts at 28 days were higher than that of the plain concrete at the same age; with better results coming from the bark extract.

(d) Eucalyptus

From Table 4.15, the optimum dosages were 10% and 40% for bark and wood extracts, respectively. From Figure 4.20, strength values at 28 days, for both extracts, were higher than that of the control concrete. For this plant, strength value of concrete containing wood extract was higher than that of concrete containing bark extract.

(e) Comparison of strength results from the admixtures

From Figure 4.20, comparing strength of the control concrete with that of concrete containing Sika plastiment BV40, the admixture lowered the strength, at all testing ages. Considering strength values, at curing age of 28 days, of concrete containing plant extracts with that of the control concrete at the same curing age, higher values were obtained with the former. At the concrete design age of 28 days, for cypress and pine extracts, higher compressive strength values were obtained for concrete containing bark extracts than for concrete containing wood extracts. For eucalyptus, the reverse was the case. Comparing the three plants, cypress, pine and eucalyptus, at the age of 28 days, concrete containing pine extracts gave the gave the highest compressive strength values. Strength results obtained with cypress and eucalyptus extracts, at 28 days were not significantly different.

For all the plants, strength values at 28 days, obtained with bark extracts, differed from the values obtained with wood extracts. The bark materials were softer than wood materials. It is therefore, reasonable to assume that lignin, more readily got into the black liquor during cooking of the barks than during cooking of the wood.

In section 2.5.1, use of Acacia plant extract as a concrete admixture was reviewed (Abdeljaleel, 2012**)**. Powder and liquid forms of Gum Arabic were used in varying dosages. Compressive strength, at the curing ages of 7, 21 and 28 days was tested. For both forms of the admixture; liquid and powder and at all dosages, the admixture was found to cause reduction of the compressive strength of concrete.

4.3.6.2 Workability

Results of workability tests for concrete containing cypress plant extracts were recorded in Tables F7 and F12. Those for concrete containing pine extracts were recorded in Tables G8 and G13, those for concrete containing eucalyptus extracts were recorded in Tables H8 and H15 while for concrete containing Sika plastiment BV40 were recorded in Table 4.3. Graphical presentations were done in Figures 4.4 and 4.7 for cypress, 4.10 and 4.13 for pine, and 4.16 and 4.19 for eucalyptus. For comparison purposes, results from these table and figures are summarized in Table 4.16. Workability tests had been carried out at constant free-water/cement ratio of 0.6055. From table 4.16, it was observed that the extracts were effective as workability agents. When compared with Sika plastiment, use of the extracts produced workability of the same order; although the required dosages were higher in the case of the plant extracts.

Table 4.16: Summary of workability tests results (constant w/c ratio of 0.6055)

Control concrete/Plant extract	Admixture	Critical dosage(%)(minimum dosage for maximum	Maximum slump (mm)	Scale factor
Control concrete	None	-	45	1.0
	Sika plastiment BV40	0.35(Recommended dosage: 0.2-0.5)	130	3.0
Cypress	Bark	15	140	3.0
	Wood	15	165	3.5
Pine	Bark	15	165	3.5
	Wood	15	165	3.5
Eucalyptus	Bark	20	165	3.5
	Wood	30	135	3.0

4.3.7 Cost benefits of using local tree extracts as admixtures

The effects of plant extracts on the strength and workability of concrete were discussed in section 4.3.6.

4.3.7.1 Strength consideration

Numerical values of concrete compressive strength, at various testing ages were given in Tables 4.9 for cypress, 4.12 for pine and 4.15 for eucalyptus. At the age of 28 days, strength increment was highest with pine admixtures: 15.9% for bark extract and 11%

for wood extract. The approximate ordinary Portland cement contents required to produce 1.0 m^3 of concrete are given in Table 4.17 (British Standards Institution, 1972)

Table 4.17: Prescribed mix for ordinary structural concrete

Concrete grade	Nominal maximum size of aggregate (mm)	20
	Slump (mm)	25-75
20	Cement (kg)	320
	Sand zone 2 (%)	35
25	Cement (kg)	360
	Sand zone 2 (%)	35
30	Cement (kg)	400
	Sand zone 2 (%)	35

(British Standards Institution, (1972): CP 110: Part1: 1972 – Table 50)

From Table 4.17, increase in strength from concrete grade 20 to 25 is 25% and from concrete grade 25 to 30 is 20%. Cement contents associated with those changes of concrete grade are 40 kg for each change of grade. The increase in strength, at 28 days, when pine bark extract was used, was 15.9%. This was insufficient to effect a full change of grade. However, it was more than sufficient to effect a change of half way between the grades. Hence, saving in cement content would have amounted to at least 20 kg.

From Appendix A, cement cost was KSh 23.00 per kg. In monetary terms, the savings in cement content, as a result of using pine bark extract would have amounted to more than Kshs. 460.00. The optimum dosage of pine bark extract was 20%. Therefore, the pine bark extract that would have been required (20% of 320 kg) to increase the strength of grade 20 concrete, say, from 20 N/mm^2 to 22.5 N/mm^2 at the age of 28 days was 64 kg. The empirical cost estimate of such an amount of extract was KShs 300.00; leading to a net saving of KShs 160.00 per m^3 of concrete.

4.3.7.2 Workability consideration

Comparison of data regarding workability was done in section 4.3.6.2. From Table 4.16, pine extracts again outperformed the others. The maximum slump values were 165 mm when both bark and wood extracts were used. Mix design calculations were presented in Appendix E. Use of the pine extracts increased the workability of concrete from a slump value of 45 mm to 165 mm. In the mix calculations, free-water content is obtained from step 2.

In Table E2, 165 mm slump is in the range 60 – 180 mm. The fine aggregates used were uncrushed while the coarse aggregates were crushed. Maximum aggregate size was 20 mm. From Table E2, numerical values of W_f and W_c of equation (E3) were 225 kg/m^3 and 195 kg/m^3, respectively. Substituting these values in equation (E3), free-water content required to achieve the workability of 60 - 180 mm slump was 215 kg/m^3.

Cement content required for the mix was computed in step 3. The free-water / cement ratio had been determined from step 1, as 0.6. Substituting free-water content of 215 kg/m^3 and free-water /cement ratio of 0.6 in equation (E4) gave the required cement content as 358.3 kg/m^3 (360 kg/m^3; to the nearest 5 kg/m^3) as compared to 315 kg/m^3 cement content output of the control concrete. The difference of 45 kg/m^3 is the saving in cement content. From Appendix A, at cement price of KSh 23.00 per kg, monetary saving amounted to Ksh 1035.00 / m^3 of concrete. From Table 4.16, the workability was achieved at a critical dosage of 15%. Therefore, the amount of the extract required was 15% of 315 kg/m^3 which was 47 kg/m^3. The empirical cost estimate of such an amount of extract was KShs 235.00; leading to a net saving of KShs 800.00 per m^3 of concrete. From Table 1.3, the cost of producing 1.0 m^3 of concrete, without using admixtures, was KSh 13,183.90. The KSh 800.00, therefore, amounts to 6% of the materials cost of concrete.

From Table 4.3, workability improvement from 45 mm to 130 mm slump was also achieved when Sika plastiment BV40 was used. For this, 0.35% dosage was used. The amount of the admixture that was required amounted to 1.1025 kg per m^3 of concrete (0.35% of 315 kg). The market price of this admixture was given in Table A2 of Appendix A. Using the price of Ksh. 212.40 per kg, the cost of the admixture amounted to KSh 234.20 per m^3 of concrete. From above, the saving in cement was KSh 1035.00. The difference of KSh 800.80 between the two amounts was the net saving from the use of Sika plastment BV40. This saving is also 6% of the total cost of KSh 13183.90 per m^3 given in Table 1.3.

However, while the savings in materials, resulting from the use of the Sika plastiment BV40 and pine extracts are the same, at 6%, the levels of workability achieved are different. Use of pine extracts resulted in maximum workability of 165 mm while Sika plastiment BV40 resulted in a maximum workability of 130 mm. Further, from Figure 4.1, the use of Sika plastiment BV40 lowered the compressive strength of concrete. From Figures 4.8 and 4.11, use of the pine extracts improved the compressive strength of the concrete at 28 days. The higher workability and compressive strength improvement give pine extracts clear advantage over the Sika plastiment BV40 as an admixture.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The specific conclusions made from the study were:

1. Basic material property tests confirmed that standard concrete making aggregates were used in this study,
2. Each of the six extracts made increased the compressive strength of the concrete at some optimum dosage. For cypress bark and wood extracts, the optimum dosages were the same at 40%. For Pine bark and wood extracts the optimum dosage were also the same at 20%. In the case of eucalyptus bark and wood extracts, the optimum dosages were different at 15% and 40%, respectively.
3. All the extracts increased workability of concrete. The increases were directly proportional to the dosage; up to a critical dosage. No further workability increases were realized with dosages higher than the critical dosages. For the cypress bark and wood extracts the critical dosages were 20% and 10%, respectively. For the pine bark and wood extracts, the critical dosages were the same and equal to 20%. For the eucalyptus, the critical dosages for the bark and wood extracts were 20% and 30%, respectively.

5.2 Recommendations

Consequently, it was recommended that further research be carried out to:

1. Devise a method that is more effective in the extraction of lignin from the lignocellulosic matrix,
2. Develop a method of removing hemicelluloses from the plant extracts,

3 Determine the most appropriate physical and chemical forms of the extracts, for use at the concrete mix production stage.

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APPENDICES

Appendix A: Building materials' prices

Table A1: Concrete materials' prices (KSh) per Tonne (Thika area: Year 2014)

Material	Amount (KSh)
Ordinary Portland cement	23,000.00
Fine aggregates (river sand)	2,000.00
Crushed rock coarse aggregate	2,000.00

Table A2: Concrete admixture prices (Nairobi: Year 2015)

Product	Pack quantity (litres)	Price (Ksh)	
		Per pack	Per litre (kg)
Sika plastiment	5	1062.00	212.40
BV40	200	21240.00	106.20

(Laxcon Hardware, 2015)

Appendix B: Proportions of constituent compounds of Portland cements

The following calculations were based on the formulae presented by R. H. Bogue (Soroka, 1979).

Case A: Alumina: Ferric oxide ratio ≥ 0.64 (Al_2O_3 / Fe_2O_3 ≥ 0.64) – (The more common case)

The percentage composition of the major constituent compounds may be calculated from the following equations:

(i) Tricalcium silicate

$$C_3S = 4.071CaO - (7.600SiO_2 + 6.718Al_2O_3 + 1.430Fe_2O_3 + 2.852SO_3) \quad (B1)$$

(ii) Dicalcium Silicate $C_2S = 2.867\ SiO_2 - 0.7544\ C_3S$ (B2)

(iii) Tricalcium Aluminate $C_3A = 2.650\ Al_2O_3 - 1.692\ Fe_2O_3$ (B3)

(iv) Tetracalcium Aluminoferrite $C_4AF = 3.043\ Fe_2O_3$ (B4)

Case B: Alumina: Ferric oxide ratio < 0.64 ($Al_2O_3 / Fe_2O_3 < 0.64$)

In cements low in Alumina (e.g. sulphate resisting cement) Alumina: Ferric oxide ratio is less than 0.64. In this case, the following equations are used:

(i) Tricalcium silicate

$$C_3S = 4.071CaO - (7.600\ SiO_2 + 4.479\ Al_2O_3 + 2.859\ Fe_2O_3 + 2.852\ SO_3) \quad \text{(B5)}$$

(ii) Dicalcium Silicate

$$C_2S = 2.867\ SiO_2 - 0.7544C_3S \quad \text{(B6)}$$

(iii) Tricalcium Aluminate $C_3A = 0.0$ (B7)

(iv) Ferrite phase $C_4AF + C_2F = 2.100\ Al_2O_3 + 1.702\ Fe_2O_3$ (B8)

In these equations CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO_3 represent the oxide contents as determined by chemical analysis. The minor constituent compounds such as TiO_2, Mn_2O_3, K_2O, Na_2O, P_2O_5, in total, amount to about 2% and are normally ignored in these calculations. The CaO (lime) content determined from oxide analysis must be corrected for free lime. The free lime content, generally, varies from 0.5% to 1% and if not determined, in the chemical analysis, its value may be estimated thus: (0.5 +1)/2= 0.75 ≈ 0.8%.

Assumptions:

Case A: Equations (1) - (4) are based on the assumption that cement consists of:

(i) Tricalcium silicate C_3S,
(ii) Dicalcium Silicate C_2S,
(iii) Tricalcium Aluminate C_3A
(iv) Ferrite phase is close to C_4AF.

Case B: Equations (5) - (8) are based on the assumption that cement consists of:

(i) Tricalcium silicate C_3S,

(ii) Dicalcium Silicate C_2S,

(iii) Tricalcium Aluminate (C_3A) content = 0.0%,

(iv) The ferrite phase consists of $C_4AF + C_2F$.

Illustration of the application of the equations:

A Portland cement chemical analysis gave the following oxide composition of cement:

Table B1: Cement percentage oxide composition

Oxide	Content, weight (%)
Lime - CaO	64.4
Silica - SiO_2	20.0
Alumina - Al_2O_3	5.8
Iron oxide - Fe_2O_3	3.2
Sulphur trioxide - SO_3	2.6
Magnesia - MgO	1.8
Sodium oxide - Na_2O	0.4
Potassium oxide - K_2O	0.3
Loss on ignition = moisture + CO_2 (both moisture and carbon dioxide are from the atmosphere).	1.8
Total	100.3

(Soroka, 1979)

Determination of the compound composition of the cement

The A/F ratio of the cement = 5.8/3.2 = 1.81> 0.64. Therefore equations (1) – (4) are to be used.

The free lime content was not determined in the chemical analysis and hence it should be estimated: (Assume free lime content = 0.8%)

Therefore, corrected lime content = 64.4 – 0.8 = 63.6%.

Substituting in equations (1) – (4):

(i) Tricalcium silicate content

C_3S = 4.071 x 63.6 – (7.600 x 20.0 + 6.718 x 5.8 + 1.430 x 3.2 + 2.852 x2.6) = 56.0%

(ii) Dicalcium silicate content C_2S = 2.867 x 20.0 – 0.7544 x 56.0 =15.1%

(iii) Tricalcium aluminate C_3A = 2.650 x 5.8 – 1.692 x 3.2 = 10.0%

(iv) Tetracalciumaluminal ferrite C_4AF = 3.043 x 3.2 = 9.7%

The total for the four major compounds = 56.0 + 15.1 + 10.0 + 9.7 = 90.8%.

Gypsum content

$CaSO_4$ (Gypsum) = CaO (Calcium oxide – lime) + SO_3 (Sulphur trioxide)

Molar proportions:

$CaSO_4$	=	CaO	+	SO_3
136		56		80

Molar ratio: ($CaSO_4$)/ (SO3) = 136/80 = 1.7,

Therefore gypsum ($CaSO_4$) content = 1.7 (SO_3) =1.7(2.6) = 4.4%.

Table B2: Summary of Portland cement compounds percentage calculations

Compound / oxide	Content, wt.%
The four compounds(C_3S+C_2S +C_3A + C_4AF)	90.8
Gypsum CaSO4	4.4
Free lime CaO	0.8
Magnesia MgO	1.8
Alkali oxides (NaO_2 + K_2O)	0.7
Loss on ignition(moisture + CO_2)	1.8
Total	100.3

Appendix C: Hydration of Portland cement

(a) Hydration equations

Setting and hardening of cement paste are brought about by hydration of cement constituents.

Hydration of tricalcium silicate ($3CaO.SiO_2$):

$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O$ (C-S-H) $+ 3Ca(OH)_2$-------------- (C1)

Molar proportions:

$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$ -------- (C1.1)

456 108 342 222

Therefore hydration of tricalcium silicate (C_3S):

(i)Produces (342) (100)/ (342+222) = 60.6 % = 61 % Calcium silicate hydrate (C – S – H)

(ii)Produces (222) (100)/ (342 + 222) = 39.4 = 39 % calcium hydroxide

(iii)Requires an amount of water = (108) / (456) = 23.7 = 24 % of its own weight for full hydration.

This reaction is exothermic: heat evolved =500 J/g.

Hydration of dicalcium silicate (2CaO.SiO2)

$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O$(C-S - H) $+Ca(OH)_2$ ---------------- (C2)

Molar proportions:

$2(2CaO.SiO_2) + 4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$ ------- (C2.1)

344 72 342 74

Therefore hydration of dicalcium silicate (C_2S):

(i) Produces (342)(100) / (342 + 74) = 82 % Calcium silicate hydrate
(ii) Produces (74)(100) / (342 + 74)= 18 % Calcium hydroxide
(iii) Requires an amount of water = (72) (100)/ (344) =21 % of its own weight for full hydration.

This reaction is exothermic: heat evolved =250 J/g.

Hydration of tricalcium aluminate ($3CaO.Al_2O_3$):

$3CaO.Al_2O_3 + 6H_2O \longrightarrow 3CaO.Al_2O_3.6H_2O$ (tricalcium aluminate hydrate) ------ (C3)

Molar proportions:

$$3CaO.Al_2O_3 + 6H_2O \longrightarrow 3CaO.Al_2O_3.6H_2O \text{------------- (C3.1)}$$

270	108	354

Therefore hydration of tricalcium aluminate (C_3A):

(i) Requires an amount of water = (108) (100)/ (270) = 40 % of its own weight for full hydration.

(ii) The reaction is exothermic: heat evolved = 850 J/g.

Hydration of tetracalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$)

$4CaO.Al_2O_3.Fe_2O_3 + CaSO_4.2H_2O + Ca(OH)_2 \longrightarrow 3CaO(Al_2O_3Fe_2O_3)\ .3CaSO4.aq$-(C4)

Molar proportions:

$4CaO.Al_2O_3.Fe_2O_3 + CaSO_4.2H2O + Ca(OH)_2 \longrightarrow 3CaO(Al_2O_3Fe_2O_3)\ .3CaSO4$-(C4.1)

326	172	74	572

Therefore, hydration of cement compounds results in Tetra Calcium Aluminoferrite reacting with:

(i) An amount of gypsum ($CaSO_4.2H_2O$) = (172) (100)/326 = 53 % of its own weight.

(ii) An amount of Calcium Hydroxide {Ca $(OH)_2$} = (74)(100)/(326) = 23 % of its own weight.

(iii) The equation is exothermic: heat evolved = 450 J/g.

(b) Heat of hydration

Table C1: Heats of hydration of the pure constituent compounds of cement

Constituent compound	Heat of hydration, (J/g)
Tricalcium silicate – $3CaO.SiO_2$	503
Dicalcium silicate – $2Ca.SiO_2$	260
Tricalcium aluminate – $3CaO.Al_2O_3$	867
TetracalciumAluminoferrite - $4CaO.Al_2O_3$.Fe2O3 - (C_4AF)	419

(Soroka, 1979**)**

The heats of hydration of the constituent compounds, when hydrated as parts of cement, because of impurities, are different from those give in Table C1.They are as given in the Table C2.

Table C2: Heats of hydration as practically found in commercial Portland cement

Constituent compounds	Heat of evolution, (J/g), at the age of:					
	3 days	7 days	28 days	90 days	1 year	6.5 years
Tricalcium silicate – $3CaO.SiO_2$	243	222	377	436	490	490
Dicalcium silicate – $2Ca.SiO_2$	50	42	105	176	226	222
Tricalcium aluminate – $3CaO.Al_2O_3$	888	1559	1378	1303	1169	1374
Tetracalcium Aluminoferrite - $4CaO.Al_2O_3$.Fe2O3 - (C_4AF)	289	494	494	410	377	465

(Soroka, 1979**)**

Heat of hydration of cement $Q_H = a (C_3S) + b (C_2S) + c (C_3A) + d (C_4AF)$

Where a, b, c and d are heats of hydration of individual constituents and (C_3S), (C_2S), (C_3A) and (C_4AF) are fractional constituents in cement (Soroka, 1979).

Illustrative example

Oxide analysis: C_3S = 45 %, C_2S = 25 %, C_3A = 10 % and C_4AF =10 %, At 1 year, Q_H = 490(0.45) + 226(0.25) + 1169(0.10) + 337(0.10) = 431 J/g

Appendix D: Concrete materials' tests

Table D1: Determination of water absorption of fine aggregates

	Sample		
	I	II	III
Mass A (g)	526.0	556.0	514.0
Mass D (g)	520.0	552.0	509.0
Percentage water absorption = (A – D)100/(D)	1.154	0.63	0.98
Mean percentage water absorption = (1.15 + 0.63 +0.98)/3	0.92		

Table D2: Determination of grading of fine aggregates

	Sample		
	I	II	III
Mass retained on the 0. 600mm sieve (g) - A	221.0	251.5	243.0
Mass passing the 0.600 mm sieve (g) - B	298.0	304.0	269.0
Total mass of the sample (g) = (A+B)	519.0	555.5	512.0
Percentage mass passing the 0.600 mm sieve = (B)(100)/(A + B)	57.42	54.73	52.54
Average percentage mass passing the 0. 600 mm sieve	55		

Table D3: Determination of water absorption for coarse aggregates

	Sample (10 mm– 5 mm)			Sample (20mm – 10 mm)		
	I	II	III	I	II	III
Mass of sample in SSD condition (g) - A	1037.0	1042.0	1015.0	1050.0	1015.5	1042.0
Mass of oven dried sample (g) – D	978.5	1002.5	1000.5	1015.0	977.5	1000.0
Water absorption (%) = (A – D)100/(D)	5.98	3.94	1.45	3.45	3.89	4.20
Average percentage value of absorption		3.79			3.85	

Appendix E: Concrete mix design calculations

The Building Research Establishment (BRE) procedure was adopted.

Mix scpecifications:

The procedures of arriving at the mix specifications are discussed in chapter three of this report. These values were:

(i) Characteristic strength f_c = 20 N/mm^2,

(ii) Workability level: 30 mm – 60 mm,

(iii) Cement content:

Maximum and minimum contents were 550 kg/m^{3}and 300 kg/m^3, respectively,

(iv) Percentage defectives = 5 %, therefore k = 1.64 (BRE, 1997)

(v) Maximum free – water /cement ratio was 0.60

Step 1: Selection of water/cement ratio

No previous information concerning the variability of strength tests involving these materials existed. Therefore, curve A of Figure E1 was used to determine the standard deviation.

$$M = (k)(s) \quad \text{(E1)}$$

Where M is the margin, k is a value appropriate to the percentage defectives permitted and s is the standard deviation. If f_c is 20 N/mm^2, from curve A of Figure E1, standard deviation s is 8 N/mm^2. Percentage defectives adopted was 5% and the appropriate value of k is 1.64. Substituting numerical values in equation E1, margin M is 13.12 N/mm^2.

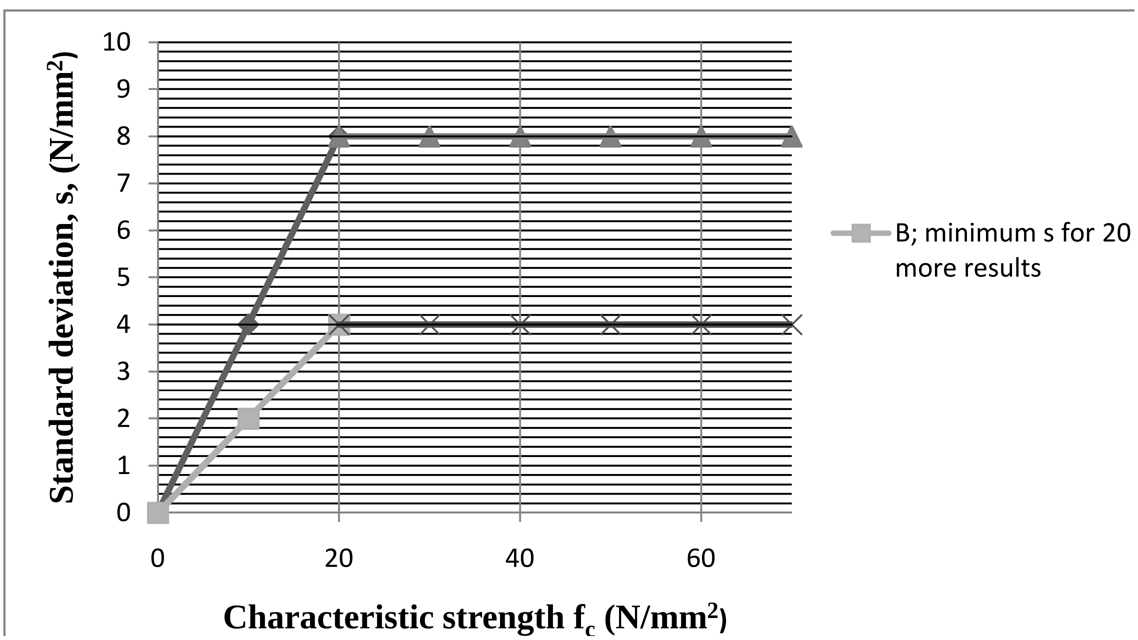

Figure E1: Relationship between standard deviation and characteristic strength (BRE, 1997)

Equation E2 determines the target mean strength.

$$f_m = f_c + M \quad \text{(E2)}$$

Where f_m = the target mean strength,

f_c = characteristic strength,

M = the margin

Substituting numerical values in equation E2, f_m is 33.12 N/mm^2

From Table E1, a mix made with the materials at hand and free water/ cement ratio of 0.5 is expected to have a compressive strength of 49 N/mm^2 at the age of 28 days. Referring to Figure E2, a design curve is drawn; parallel the printed curves, starting from point (0.5, 49) to the right until its ordinate value reaches 33.12 N/mm^2. The corresponding abscissa is the required

Table E1: Approximate compressive strength of concrete mixes (w/c ratio of 0.5)

Cement strength class	Type of coarse aggregates	Compressive strengths (N/mm^2) Age (days)			
		3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

(BRE, 1997)

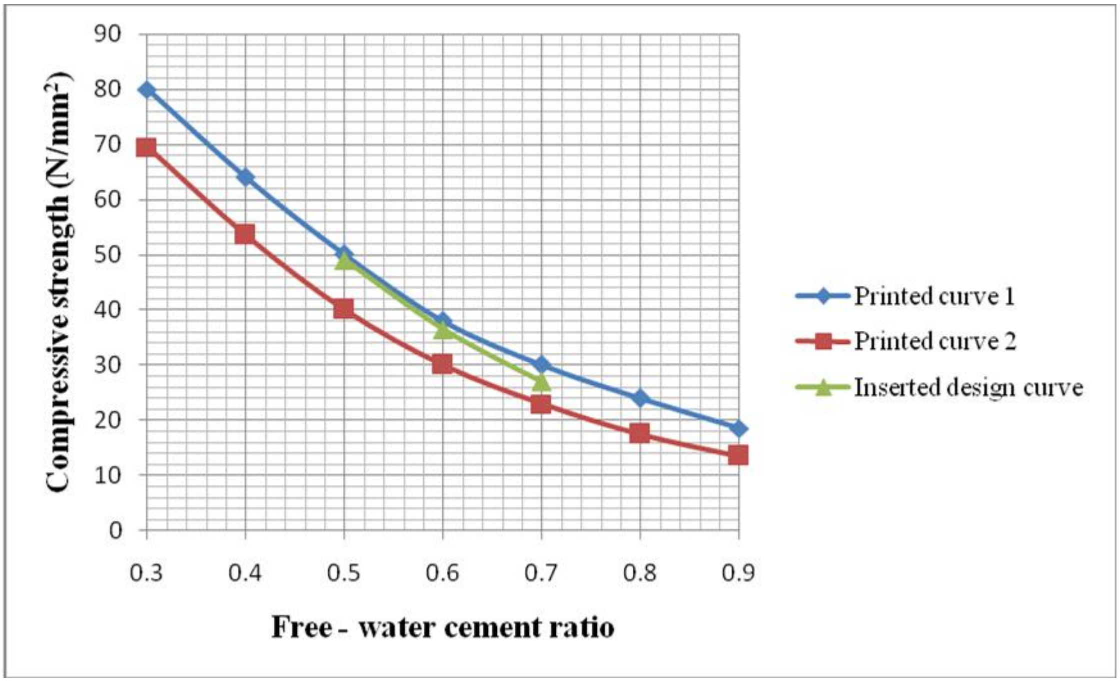

Figure E2: Relationship between compressive strength and free- water / cement ratio (BRE, 1997

Free – water cement ratio. From figure E2, the required free – water cement ratio was 0.64 > maximum allowed. Hence adopted free – water cement ratio was 0.6.

Step 2: Selection of free - water content

TableE2: Approximate free–water contents (kg/m³) required

Slump (mm)		0 - 10	10 - 30	30 - 60	60 - 180
Maximum size of aggregates	Type of aggregates				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

(BRE, 1997)

The maximum size of crushed rock coarse aggregates particle is 20 mm. The type of fine aggregates to be used is river sand (uncrushed). The necessary amount of free water, W, to attain the workability level of 30 mm – 60 mm slump is given by the equation

$$W = \left(\frac{2}{3}\right)W_f + \left(\frac{1}{3}\right)W_c \qquad \text{(E3)}$$

Where W_f = amount of free water required when fine aggregates are used, and

W_c = amount of free water required when coarse aggregates are used.

The numerical values of W_f and W_c are 180 kg/m^3 and 210 kg/m^3, respectively. Substituting numerical values in equation (E3), free –water content is found to be 190 kg/m^3.

. Step 3: Determination of cement content

The cement content is determined from equation E4:

$$Cement\ content = \frac{free - water\ content}{\frac{free - water\ content}{cement\ content}} \quad (E4)$$

Free – water content, from step 2, was 190 kg/m^3, and the adopted free – water cement ratio from step 1 was 0.60. Substituting these values in equation (E4), cement content was found to be 315 kg/m^3 (to the nearest 5 kg/m^3). Maximum and minimum cement contents specified were 550kg/m^3 and 300 kg/m^3. Hence the calculated amount is acceptable.

Step 4: Determination of the total aggregate content

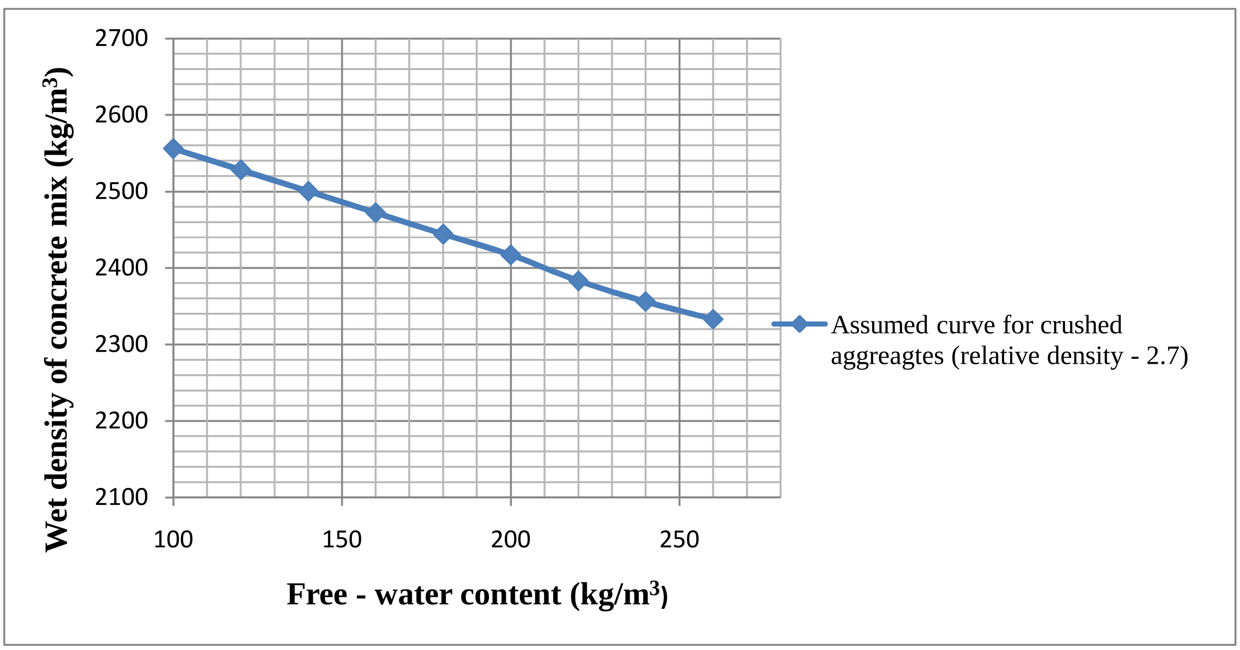

Figure E3: Estimated wet density of fully compacted concrete (BRE, 1997)

The free – water content from step 3 is 190 kg/m^3. From figure E3, the wet density D is 2428 kg/m^3.

$$\text{Total aggregate content} = D - C - W \qquad \text{(E5)}$$

Where, D = the wet density of the concrete (kg/m^3)

C = the cement content (kg/m^3)

W = the free – water content (kg/m^3)

Substituting numerical values in equation E5, total aggregates content was 1923 kg/m^3.

Step 5: Selection of fine and coarse aggregates contents

Maximum aggregate size: 20 mm

Slump: 30 – 60 mm

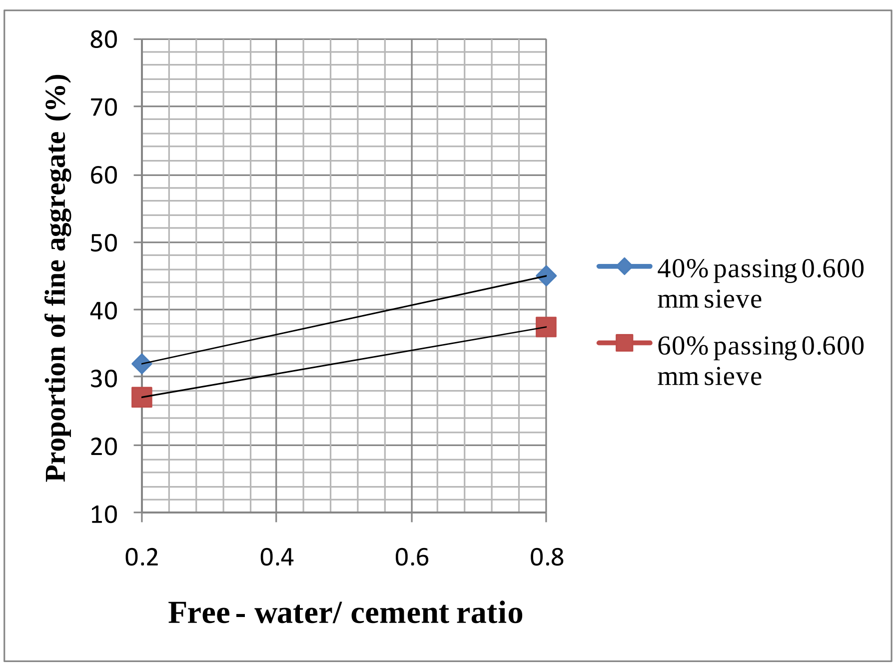

Figure E4: Recommended proportions of fine aggregates (BRE, 1997)

From section 4.1, the percentage passing the 0.600 mm sieve was 55%, and the free – water/ cement ratio adopted was 0.60. Referring to figure E4, the proportion of the fine aggregates was 35% of the total aggregates which is 675 kg/m^3 (to the nearest 5 kg/m^3). Coarse aggregates content was therefore 1248 kg/m^3.

Step 6: Constitution of coarse aggregates

The coarse aggregate was made from 10 mm and 20 mm single sized aggregates in the ratio 1: 2, respectively. Hence, coarse aggregate (10 mm single size) content was 416 kg/m^3 while that for 20 mm single size was 832 kg/m^3.

Step 7: Allowance for aggregates water absorption

Oven dried aggregates were used for the concrete production. Mix design data was on the basis of aggregates in saturated surface dry (SSD) moisture condition. The quantities obtained in the mix design calculations were adjusted to allow for the water required to bring the aggregates to SSD condition **(**BRE 1997**).**

(a) Fine aggregates:

Section 4.1, experimentally determined absorption for the fine aggregates, A was 0.92%

$$The\ required\ mass\ of\ oven\ dry\ fine\ aggregates = \frac{(mass\ of\ fine\ aggregates\ at\ SSD\ condition)(100)}{(100 + A)} \qquad (E6)$$

Substituting numerical values in equation E6

$$The\ required\ mass\ of\ oven\ dry\ fine\ aggregat = \frac{(675)(100)}{(100 + 0.92)} = 668.8466\ kg/m^3$$

The amount of water required for absorption = (0.92/100) (668.8466) = 6.1534 kg/m^3

(b) Coarse aggregates

(i) Coarse aggregates (10 mm single size)

From section 4.1, absorption A was 3.79%.

:. The required mass of oven dry 10 mm single sized aggregates

= (mass of 10 mm aggregates in SSD condition) x (100) / (100 + A) = (416) x (100) / (100 + 3.79)

= 400.8093 kg / m^3 = 400 kg/m3 (to the nearest 5 kg/m^3)

The amount of water required for absorption = (3.79 /100) (400.8093) =15.1907 kg/m^3

(ii) Coarse aggregates (20 mm single size)

From section 4.1, absorption A was 3.85%.

:. The required mass of oven dry 20 mm single sized coarse aggregates

= (mass of 20 mm aggregates in SSD condition) x (100) / (100 + A)

= (832) x (100) / (100 + 3.85),

= 801.1555 kg/m^3 = 800 kg/m^3 (to the nearest 5 kg/m^3)

The amount of water required for absorption = (3.85/ 100) 801.1555 = 30.8445 kg/m^3.

Total water for absorption = 6.1534 + 15.1907 + 30.8445 = 52.1886 kg/m^3

Total water requirement =190 + absorption =190 + 52.1886 = 242.1886 kg / m^3

The cement contents for trial mixes may be taken as 315 kg/m^3, 365 kg/m^3, and 400 kg/m^3 (BRE 1997).

Cement content of 400 kg/m^3gave results that were preferred.

Table E3: Mix design output materials summary

Quantities	Cement (kg)	Water	Fine aggregates	Coarse aggregates (kg)		
				10 mm	20 mm	40 mm
Per m^3	400	242.1886	670	400	800	-
Per trial mix of --------- m^3						

(BRE, 1997)

During casting, allowance for waste of materials was taken as 15%.

Appendix F: Concrete containing Cypress tree extracts as admixtures

(a) Cypress bark extract

Table F1: Cypress tree bark extract (dosage 10%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	63.145	6.5	6.0	0.6379	45	45 ± 5
		48.038	5.0				
		69.451	7.0				
7	10000	133.324	13.5	13.5			
		137.724	14.0				
		130.241	13.0				
28	10000	174.878	17.5	21.5			
		233.209	23.5				
		232.312	23.5				
61	10000	301.894	30.0	29.0			
		287.112	28.5				
		285.599	28.5				

Table F2: Cypress tree bark extract (dosage 20 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	93.610	9.5	8.5	0.6193	50	45 ± 5
		63.089	6.5				
		87.584	9.0				
7	10000	170.480	17.0	17.0			
		183.816	18.5				
		161.795	16.0				
28	10000	313.831	31.5	32.5			
		333.887	33.5				
		324.899	32.5				
61	10000	380.072	38.0	38.5			
		390.269	39.0				
		387.936	39.0				

Table F3: **Cypress tree bark extract (dosage 30%)**

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	214.297	21.5	22.5	0.6055	50	45 ± 5
		227.969	23.0				
		231.387	23.0				
7	10000	263.466	26.5	25.5			
		253.408	25.5				
		251.699	25.0				
28	10000	316.754	31.5	36.5			
		392.629	39.5				
		379.668	38.0				
61	10000	394.615	39.5	43.5			
		437.886	44.0				
		469.702	47.0				

Table F4: Cypress tree bark extract (dosage 40 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	294.368	29.5	29.5	0.6157	45	45 ± 5
		288.793	29.0				
		306.141	30.5				
7	10000	336.677	33.5	32.0			
		297.702	30.0				
		325.142	32.5				
28	10000	460.596	46.0	45.0			
		450.235	45.0				
		443.300	44.5				
61	10000	527.845	53.0	52.0			
		546.180	54.5				
		489.442	49.0				

Table F5: Cypress tree bark extract (dosage 47.5 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
						Actual	Target
			Sample stress	Mean stress			
3	10000	294.368	22.5	22.5	0.6055	45	45 ± 5
		288.793	21.0				
		306.141	23.5				
7	10000	336.677	29.5	29.0			
		297.702	29.5				
		325.142	27.5				
28	10000	460.596	33.5	34.5			
		450.235	35.5				
		443.300	35.0				
61	10000	527.845	34.5	35.0			
		546.180	38.5				
		489.442	32.5				

Table F6: Computation for linear correlation r (data from Table 4.6)

							Σ_s
Percentage dosage = x	0	10	20	30	40	47.5	147.5
The 28 day mean stress = y	41	35.5	40.5	39.5	40.5	39.5	236.5
xy	0	355	810	1185	1620	1876.25	5846.25
x^2	0	100	400	900	1600	2256.25	5256.5
y^2	1681	1260.25	1640.25	1560.25	1640.25	1560.25	9342.25

$$Correlation\ coefficient\ r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (F1)$$

The number of the sets of data n = 6.

Substituting numerical values, from Table F6, in equation (F1):

$$Correlation\ coefficient\ r = \frac{(6)(5846.25) - (147.5)(236.5)}{\sqrt{[(6)(5256.5) - (147.5)^2][(6)(9342.25) - (236.5)^2]}}$$

$$= \frac{35077.5 - 34883.75}{\sqrt{[31539 - 21756.25][56053.5 - 55932.25]}}$$

$$= \frac{193.75}{\sqrt{[9782.75][121.25]}} = \frac{193.75}{1089.109011} = 0.17789771$$

$$= 0.178$$

Since 0.178 > 0.0, then, there exists a linear correlation between the dosage and the stress. Hence

linear relationship between stress y and dosage x is defined by the equation:

$$y = a + bx \qquad (F2)$$

$$where\ b = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2} \qquad (F2.1)$$

$$and\ a = \frac{\sum y - b\sum x}{n} \qquad (F2.2)$$

Substituting numerical values, from Table F6, in equations (F2.1), and (F2.2):

$$b = \frac{(6)(5846.25) - (147.5)(236.5)}{(6)(5256.5) - (147.5)^2} = \frac{35077.5 - 34883.75}{31539 - 21756.25} = \frac{193.75}{9782.75} = 0.0198052$$
$$= 0.0198$$

$$a = \frac{236.5 - (0.0198)(147.5)}{6} = 38.92978713 = 38.93$$

Hence, stress y = 0.0198x + 38.93.

Where x = cypress bark extract dosage (Walpole, R.E. 1986).

Table F7: Slump values obtained with different dosages of the cypress bark extract

Cypress bark extract as a mass percentage of the cement content	w/c	Slump (mm)
0	0.6055	45
10	0.6055	115
20	0.6055	135
30	0.6055	135
40	0.6055	140
47.5	0.6055	135

(b) Cypress wood extract

Table F8: Cypress tree wood extract (dosage 10.0%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	215.137	21.5	21.0	0.59	3.0	45	45 $\pm$ 5
		205.276	20.5					
		212.672	21.5					
7	10000	273.636	27.5	27.5				
		284.703	28.5					
		265.343	26.5					
28	10000	393.871	39.5	44.5				
		476.574	47.5					
		470.498	47.0					
61	10000	413.836	41.5	45.0				
		456.882	45.5					
		485.140	48.5					

Table F9: Cypress tree wood extract (dosage 20.0%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	168.967	17.0	18.0	0.57	5.5	45	45 ± 5
		179.417	18.0					
		186.897	18.5					
7	10000	273.048	27.5	29.0				
		308.978	31.0					
		290.194	29.0					
28	10000	429.414	43.0	45.0				
		446.020	44.5					
		481.110	48.0					
61	10000	480.000	38.0	46.0				
		475.000	37.5					
		425.000	32.5					

Table F10: Cypress tree wood extract (dosage 40.0%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	201.617	20.0	26.0	0.57	5.7	40	45 ± 5
		253.100	25.3					
		200.777	26.0					
7	10000	257.162	25.5	28.0				
		285.599	28.5					
		303.938	30.5					
28	10000	444.918	44.5	44.0				
		417.401	41.5					
		466.454	46.5					
61	10000	523.286	52.5	51.5				
		534.668	53.5					
		487.808	49.0					

Table F11: Average stress values at different ages and the relevant slump values

Cypress wood extract as a mass percentage of the cement	Mean compressive stress (N/mm^2)				Water reduction (%)	Slump (mm)	
	3 days	7 days	28 days	61 days		Actual	Target
0.0	18.0	31.0	41.0	48.0	0.0	45	45 ± 5
10.0	21.0	27.5	44.5	45.0	3.0	45	
20.0	18.0	29.0	45.0	46.0	5.5	45	
40.0	22.0	28.0	44.0	51.5	5.7	40	

Table F12: Slump values for different dosages of the cypress wood extract

Cypress bark extract as a mass percentage of the cement content	w/c	Slump (mm)
0	0.6055	45
10	0.6055	160
20	0.6055	155
30	0.6055	165
40	0.6055	155
47.5	0.6055	145

Appendix G: Concrete containing Pine tree extracts as admixtures

(a) Pine bark extracts

Table G1: Pine tree bark extract (dosage 10 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	251.391	25.0	25.5	0.5937	40	45 ± 5
		252.736	25.0				
		259.796	26.0				
7	10000	361.203	36.0	32.0			
		311.280	31.0				
		296.553	29.5				
28	10000	465.054	46.5	47.5			
		507.796	51.0				
		445.352	44.5				
61	10000	509.257	51.0	48.5			
		464.755	46.5				
		478.072	48.0				

Table G2: Pine tree bark extract (dosage 20 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	254.137	25.5	24.0	0.6055	50	45 ± 5
		210.795	21.0				
		250.495	25.0				
7	10000	334.021	33.5	34.5			
		357.585	36.0				
		337.038	33.5				
28	10000	479.725	48.0	47.5			
		485.118	48.5				
		463,368	46.5				
61	10000	547.316	54.5	54.5			
		537.379	53.5				
		554.662	55.5				

Table G3: Pine tree bark extract (dosage 30 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	247.048	24.5	24.5	0.6055	40	45 ± 5
		246.292	24.5				
		238.391	24.0				
7	10000	297.002	29.5	30.5			
		335.176	33.5				
		291.987	29.0				
28	10000	471.334	47.0	46.0			
		440.678	44.0				
		475.701	47.5				
61	10000	479.593	48.0	48.5			
		434.326	43.5				
		543.111	54.5				

Table G4: Pine tree bark extract (dosage 40 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	247.048	25.0	25.5	0.5905	45	45 ± 5
		246.292	26.5				
		238.391	25.5				
7	10000	297.002	25.5	27.5			
		335.176	26.5				
		291.987	30.5				
28	10000	471.334	51.5	48.0			
		440.678	40.0				
		475.701	52.0				
61	10000	479.593	51.5	52.0			
		434.326	51.5				
		543.111	53.0				

Table G5: Pine tree bark extract (dosage 47.5 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
						Actual	Target
			Sample stress	Mean stress			
3	10000	214.942	21.5	23.0	0.5905	50	45 ± 5
		243..854	24.5				
		234.049	23.5				
7	10000	345.348	34.5	33.5			
		336.413	33.5				
		322.491	32.5				
28	10000	434.005	43.5	43.5			
		435.216	43.5				
		437.768	44.0				
61	10000	465.831	46.5	48.0			
		455.414	45.5				
		522.310	52.0				

Table G6: Average stress values at different ages and the relevant mix slump test values

Pine bark extract as a mass percentage of the cement content	Mean compressive strength (N/mm^2)				Slump (mm)	
	3 days	7 days	28 days	61 days	Actual	Target
0.0	18.0	31.0	41.0	48.0	45	45 $\pm$ 5
10.0	25.5	32.0	47.5	48.5	40	
20.0	24.0	34.5	47.5	54.5	50	
30.0	24.5	30.5	46.0	48.5	40	
40.0	25.5	27.5	48.0	52.0	50	
47.5	23.0	33.5	43.5	48.0	50	

Table G7: The 28 days stress for pine bark extract

Cypress bark extract as a mass percentage of the cement used	w/c ratio	Area (mm^2)	Load (kN)	The 28 days compressive strength (N/mm^2)	
				Sample strength	Mean strength
0	0.6055	10000	410.912	41.091	41.0
			395.788	39.579	
			432.312	43.231	
10	0.6055	10000	407.080	40.708	38.5
			379.293	37.929	
			370.331	37.033	
20	0.6055	10000	380.142	38.014	39.0
			365.298	36.530	
			426.020	42.602	
30	0.6055	10000	438.790	43.879	44.0
			427.010	42.701	
			457.395	45.740	
40	0.6055	10000	398.948	39.895	44.0
			476.212	47.621	
			449.531	44.953	
47.5	0.6055	10000	441.099	44.110	42.5
			398.542	39.854	
			428.738	42.874	

Table G8: Slump for concrete containing different dosages of the pine bark extract

Pine bark extract as a mass percentage of the cement content	w/c ratio	Slump (mm)
0	0.6055	45
10	0.6055	155
20	0.6055	160
30	0.6055	165
40	0.6055	140
47.5	0.6055	150

(b) Pine wood extracts

Table G9: Pine tree woods extract (dosage 10.0 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	216.679	21.5	21.0	0.57875	4.4	50	45 ± 5
		208.946	21.0					
		205.892	20.5					
7	10000	266.548	26.5	27.5				
		281.873	28.0					
		273.664	27.5					
28	10000	405.512	40.5	43.0				
		437.137	43.5					
		443.979	44.5					
61	10000	549.299	55.0	51.0				
		503.630	50.5					
		468.153	47.0					

Table G10: Pine tree woods extract (dosage 20.0 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	198.160	20.0	20.0	0.57069	5.8	40	45 ± 5
		205.332	20.5					
		188.410	19.0					
7	10000	293.892	29.5	28.5				
		287.084	28.5					
		280.584	28.0					
28	10000	460.831	46.0	45.5				
		448.826	45.0					
		461.228	46.0					
61	10000	515.330	51.5	50.5				
		493.703	49.5					
		509.029	51.0					

Table G11: Pine tree woods extract (dosage 40.0 %)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	222.534	22.5	22.5	0.5777	4.6	50	45 ± 5
		219.256	22.0					
		223.150	22.5					
7	10000	272.123	27.0	28.0				
		279.547	28.0					
		296.413	29.5					
28	10000	375.321	37.5	41.5				
		408.695	41.0					
		463.730	46.5					
61	10000	516.888	51.5	51.5				
		500.851	50.0					
		523.161	52.5					

Table G12: Average stress values at different ages and the relevant slump values

Pine wood extract as a mass percentage of the cement content	Mean compressive stress (N/mm^2)				Water reduction (%)	Slump (mm)	
	3 days	7 days	28 days	61 days		Actual	Target
0.0	18.0	31.0	41.0	48.0	0.0	45	45 $\pm$ 5
10.0	21.0	27.5	43.0	51.0	4.4	50	
20.0	20.0	28.5	45.5	50.5	5.8	40	
40.0	22.5	28.0	41.5	51.5	4.6	50	

Table G13: slump values for different dosages of the pine wood extract

Pine wood extract as a mass percentage of the cement used	w/c ratio	Slump (mm)
0	0.6055	45
10	0.6055	150
20	0.6055	165
30	0.6055	145
40	0.6055	145
47.5	0.6055	75

Appendix H: Concrete containing Eucalyptus tree extracts as admixtures

(a) Eucalyptus bark extracts

Table H1: Eucalyptus tree bark extract (dosage 10%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	201.578	20.5	21.5	0.5913	45	45 ± 5
		222.674	22.5				
		216.510	21.5				
7	10000	295.657	29.5	30.0			
		313.931	31.5				
		286.972	28.5				
28	10000	430.072	43.0	43.5			
		422.974	42.5				
		445.227	44.5				
61	10000	476.756	47.5	49.5			
		493.103	49.5				
		513.539	51.5				

Table H2: **Eucalyptus tree bark extract (dosage 20%)**

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	222.330	22.0	25.0	0.6055	45	45 ± 5
		234.974	23.5				
		296.637	29.5				
7	10000	326.094	32.5	32.5			
		331.272	33.0				
		317.625	32.0				
28	10000	396.955	39.5	36.5			
		376.103	37.5				
		322.099	32.0				
61	10000	460.719	46.0	44.0			
		402.230	40.0				
		452.802	45.5				

Table H3: Eucalyptus tree bark extract (dosage 30%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	205.248	20.5	22.0	0.6004	45	45 ± 5
		238.812	24.0				
		214.970	21.5				
7	10000	358.527	36.0	34.5			
		338.249	34.0				
		335.182	33.5				
28	10000	401.611	40.0	42.0			
		427.996	43.0				
		430.681	43.0				
61	10000	435.199	43.5	44.5			
		466.429	46.5				
		439.870	44.0				

Table H4: Eucalyptus tree bark extract (dosage 40%)

Duration (days)	Area (mm^2)	Load (kN)	Stress(N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	196.731	19.5	22.0	0.6055	40	45 $\pm$ 5
		220.180	22.0				
		241.725	24.0				
7	10000	308.749	31.0	29.0			
		276.858	27.5				
		290.446	29.0				
28	10000	351.045	35.0	38.0			
		372.312	37.0				
		413.364	41.5				
61	10000	463.900	46.5	43.5			
		442.319	44.0				
		395.405	39.5				

Table H5: Eucalyptus tree bark extract (dosage 47.5%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Slump (mm)	
			Sample stress	Mean stress		Actual	Target
3	10000	194.574	19.5	20.0	0.6055	45	45 ± 5
		190.203	19.0				
		221.078	22.0				
7	10000	279.408	28.0	30.0			
		295.545	29.5				
		317.362	32.0				
28	10000	371.240	37.0	39.0			
		37.792	37.0				
		427.792	43.0				
61	10000	443.099	44.5	47.5			
		476.053	47.5				
		501.341	50.0				

Table H6: Average stress values at different ages and the relevant slump values

Eucalyptus bark extract as a mass percentage of the cement content	Mean compressive stress (N/mm^2)				Slump (mm)	
	3 days	7 days	28 days	61 days	Actual	Target
0.0	18.0	31.0	41.0	48.0	45	45 ± 5
10.0	21.5	30.0	43.5	49.5	45	
20.0	25.0	32.5	36.5	44.0	45	
30.0	22.0	34.5	42.0	44.5	45	
40.0	22.0	29.0	38.0	43.5	40	
47.5	20.0	30.0	39.0	47.5	45	

Table H7: Strength for different dosages of eucalyptus tree bark extract (constant w/c ratio)

Eucalyptus bark extract % mass of cement	w/c ratio	Area (mm^2)	Load (kN)	The 28 days compressive strength (N/mm^2)	
				Sample strength	Mean strength
0	0.6055	10000	410.912	41.091	41.0
			395.788	39.579	
			432.312	43.231	
10	0.6055	10000	264.559	26.456	31.0
			298.396	29.840	
			364.329	36.433	
20	0.6055	10000	430.367	43.037	37.0
			385.018	38.502	
			297.814	29.781	
30	0.6055	10000	311.280	31.128	35.5
			376.442	37.644	
			369.727	36.973	
40	0.6055	10000	268.509	26.851	33.5
			368.112	36.811	
			362.712	36.271	
47.5	0.6055	10000	412.392	41.239	41.0
			390.992	39.099	
			429.767	42.977	

Table H8: Slump values obtained with different dosages of the eucalyptus bark extract

Eucalyptus bark extract as a mass percentage of the cement content	w/c ratio	Slump (mm)
0	0.6055	45
10	0.6055	145
20	0.6055	165
30	0.6055	165
40	0.6055	155
47.5	0.6055	150

(b) Eucalyptus wood extract

Table H9: Eucalyptus tree wood extract (dosage 10.0%)

Duration (days)	Area (mm^2)	Load (kN)	Stress (N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	218.108	22.0	21.0	0.5955	1.7	50	45 ± 5
		217.071	21.5					
		201.550	20.0					
7	10000	283.806	28.5	28.5				
		272.516	27.5					
		292.688	29.5					
28	10000	411.139	41.0	41.5				
		413.459	41.5					
		424.864	42.5					
61	10000	405.605	40.5	42.0				
		451.579	45.0					
		409.963	41.0					

Table H12: Eucalyptus tree wood extract (dosage 20.0%)

Duration (days)	Area (mm^2)	Load (kN)	Stress(N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	202.937	20.5	21.0	0.5829	3.7	45	45 ± 5
		231.140	23.0					
		191.843	19.0					
7	10000	287.644	29.0	29.0				
		300.397	30.0					
		278.987	28.0					
28	10000	423.852	42.5	43.5				
		437.031	43.5					
		448.773	45.0					
61	10000	465.939	46.5	47.0				
		490.688	49.0					
		450.100	45.0					

Table H13: Eucalyptus tree wood extract (dosage 40.0%)

Duration (days)	Area (mm^2)	Load (kN)	Stress(N/mm^2)		w/c	Water reduction (%)	Slump (mm)	
			Sample stress	Mean stress			Actual	Target
3	10000	246.180	24.5	24.5	0.5578	7.9	50	45 ± 5
		258.064	26.0					
		230.920	23.0					
7	10000	317.382	31.5	30.5				
		301.655	30.0					
		297.366	29.5					
28	10000	409.895	41.0	45.0				
		463.302	46.5					
		471.961	47.0					
61	10000	483.169	48.5	46.0				
		424.760	42.5					
		470.877	47.0					

Table H14: Average stress values at different ages and the relevant slump values

Eucalyptus wood extract as a mass percentage of the cement content	Mean compressive stress (N/mm^2)				Water reduction (%)	Slump (mm)	
	3 days	7 days	28 days	61 days		Actual	Target
0.0	18.0	31.0	41.0	48.0	0.0	45	45 ± 5
10.0	21.0	28.5	41.5	42.0	1.7	50	
20.0	21.0	29.0	43.5	47.0	3.7	45	
40.0	24.5	30.5	45.0	46.0	7.9	50	

Table H15: Slump values obtained with different dosages of the eucalyptus wood extract

Cypress bark extract as a mass percentage of the cement content	w/c ratio	Slump (mm)
0	0.6055	45
10	0.6055	60
20	0.6055	60
30	0.6055	135
40	0.6055	55
47.5	0.6055	60