DEVELOPMENT OF WATERPROOFING AGENT FOR CEMENT SOIL BLOCKS FROM LOW DENSITY POLYETHYLENE WASTES

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Development of Waterproofing Agent for Cement Soil Blocks from Low Density Polyethylene Wastes

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DECLARATION

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

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This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

To my wife, Loise Nyakeru and daughter Joy Njeri whose moral and material support made it possible for me to complete this work.

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of this research and I am asking God to bless you. All praise is to God through Jesus Christ.

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LIST OF ACRONYMS

CSB	Cement soil blocks
HDP	High density polyethylene
ILO	International Labour Office
KEBS	Kenya Bureau of Standards
KNCPC	Kenya National Cleaner Production Centre
KS	Kenya Standard
LDP	Low density polyethylene
POPs	Persistent Organic Pollutants

ABSTRACT

Low density polyethylene (LDP) is an essential element of industrialization and socio-economic development of a country. This is due to the universal use of low density polyethylene in other sectors of the economy. However, the problem arises from the management of LDP waste. If burned, LDP infuse the air with toxic fumes which have been linked with cases of cancer. When animals, fish or birds ingest LDP, they eventually die due to its indigestibility. When LDP is littered, it is carried by wind and rain storms and it clogs drainage and sewer lines. The current methods for managing LDP waste materials which include injection moulding, blow moulding and film moulding are inadequate. About 2,000 tons of LDP end up into the waste stream every month in Kenya.

This study sought to develop a method for converting LDP into waterproofing agent for cement soil blocks (CSB's). Red soil was stabilized with cement and then compressed to make CSB's. Through heating, LDP was liquefied and the melt applied on CSB's through immersion. The LDP melt formed a uniform coat on CSB's after cooling. When the melt was put in an air tight container and allowed to cool at room temperature for 24 hrs, it solidified. Kerosene was added in to the LDP melt to stop solidification after cooling to room temperature at the ratio of LDP : Kerosene; 1 : 2 v/v. Since the improved melt dry film easily peeled off, long drying oil alkyd resin was added at the

ratio of LDP : Kerosene : resin; 1: 2 : 3 v/v. The resulting dry film was transparent. To increase its hiding power, red iron oxide was added to the improved melt until the optimum pigment volume concentration (PVC) was achieved. This was achieved by establishing the scattering coefficient of the dry films of the improved melts.

The improved melt with the highest hiding power was given by LDP : Kerosene : Resin : Red iron Oxide; (1 : 2 : 3) : 0.2 m/m. This formulation had 23.1 % pigment volume concentration, 86.7 µm scattering coefficient, 34.7 m^2/l spreading rate, 0.0288 l/m^2 usage rate, 9.66 Ksh/m^2 per hiding power, 335 Ksh/l and 40 µm opacity. It was free of gel, coarse particles and skin. It produced a homogenous product of uniform consistency after stirring manually, was easy to brush, had satisfactory flowing, spreading and leveling properties, its dry film had no signs of sagging, running and had no brush marks. It did not exhibit any cracking or colour fading when tested for resistance to accelerated weathering. CSB's coated with this formulation did not absorb water after immersing them in water for 30 days.

The improved melt (LDP : Kerosene : Resin : Red iron Oxide; (1 : 2 : 3) : 0.2 m/m) was reformulated to investigate the compromise between improving opacity and increasing formulation costs. This was done by using constant amount of red iron oxide while varying LDP, kerosene and resin. The best formulation was given by LDP : Kerosene : Resin : Red iron Oxide; (1 : 2 : 57) : 0.2 m/m. This formulation had 17.1 % PVC, 116.7

% volume solids, 46.7 m^2/l spreading rate, 21.4 l/m^2 usage rate, 5.9 µm scattering coefficient, 528.5 Ksh per liter and cost per hiding power of 11.3 Ksh/ m^2.

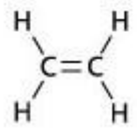
The formulations developed had a mean of 10.6, standard deviation of 0.5 and coefficient of variation of 0.05. Since their coefficient of variation was less than 1, the cost of covering a given area did not change significantly. However, the cost will change if price of any of the raw materials changes. LDP : Kerosene : Resin : Red iron Oxide; (1 : 2 : 57) : 0.2 m/m formulation gave the desired waterproofing agent for protecting CSB's.

CHAPTER ONE

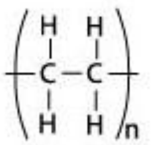
1.0 INTRODUCTION

1.1 Background

Low density polyethylene (LDP) is a thermoplastic made from the monomer ethylene. The ethylene molecule is C_2H_4 (CH_2=CH_2)



Ethylene



Polyethylene Polymer

LDP was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries using a high pressure process through free radical polymerization. Its manufacture employs the same method today (Dennis, 2010).

When LDP litter is carried by wind and rain storms it clogs drainage and sewer lines. This is a common feature in our urban areas causing flooding. LDP remains in the environment for a long period of time exacerbating the above effects. Proper management can mitigate this problem. It is therefore, important to develop methods which will help to reduce the amount of LDP getting into the waste stream.

Research findings by (Bamford, *et al*., 2008) attributes many deaths of several species of birds, whales, turtles, and other marine species to entanglement by LDP litter and consumption of the same. LDP is incapable of being digested, which can lead to false satiation and ultimately to starvation.

Research findings by (Saloranta, *et al*., 2006) have shown that LDP is capable of absorbing polychlorinated biphenyls and dichlorodiphenylethylene. This occurs through the attraction of the hydrophobic chemicals to the non-polar surfaces of LDP. Persistent Organic Pollutants (POPs) such as Polychlorinated dibenzo-*p*-dioxins and dibenzofurans also are hydrophobic and can attach to LDP particles. POPs have been attributed to reproductive impairment in marine mammals (Bamford, *et al*., 2008), lowering fecundity rates (Secchi and Zarzur, 1999) and creating challenges in the conservation of endangered species (Lambertsen, *et al*., 2005). The lightweight and durable characteristics of LDP have created a medium for organisms to raft to alternate ecosystems. Once colonized by fungi or barnacles, the buoyancy of LDP materials allow the species to travel thousands of miles where they could potentially be invasive and disrupt ecosystem processes (Mato, *et al*., 2001).

The geology and physical composition of many areas have been altered by the presence of LDP materials (Williams and Simmons 1996). The Pacific Ocean, North of the

Hawaiian Islands has an artificial island from the accumulation of approximately three million tons of LDP debris (Fitzgerald, 2008). When LDP finds its way into sewer pipes, it blocks them making them to burst (KNCPC, 2006). LDP waste is more costly to recycle than other plastics because it is more difficult to separate from other solid waste before recycling (KNCPC, 2006). There is reluctance from industries to take on that extra cost.

1.2 Low Density Polyethylene in Kenya

Low density polyethylene bags in Kenya are a major source of litter in the waste stream. The problem with LDP bags is that they are victims of their own success. They are so cheap to manufacture that, at a cost of US$0.01 per bag, retailers often absorb the price of bags into the price of merchandise they sell. (Wikinews, 2005).

This makes the bag appear free to the consumers, who in turn do not value it, and throw the bag away with little reuse. In a vicious circle, the low cost of the bags drives down the amount of material used to manufacture them, creating bags that are flimsy and not easy to reuse. In Kenya, 4,000 tons of LDP bags are produced each month and only half of this amount is recycled (UNEP, 2005). The other half is left piling up in environment causing serious environmental degradation.

This study sought to develop a method for converting LDP into waterproofing agent for CSBs. CSBs are easily destroyed by water since they have pores which allow them to absorb water. This waterproofing agent will positively contribute towards the promotion of CSB technology which is environmentally friendly.

1.3 Scope of the Study

This study focused on developing a method for converting LDP into a useful product which can be used to water proof CSB's.

1.4 Statement of the Problem

Although there are many methods of handling low density polyethylene (LDP) waste like landfilling, incineration, deep well injection, recycling and reusing, they don't help to manage all the LDP generated. Proper management can mitigate this problem. It is therefore, important to develop better methods which will help to reduce the amount of LDP from getting into the environment. It is therefore, necessary to develop a method that will help to convert LDP wastes into a waterproofing agent for cement soil blocks

1.5 Justification of the Study

Once used, LDP becomes litter and finds its way into the environment. If burned, they infuse the air with toxic fumes which contain chemicals, including dioxins, which have been linked with cases of cancer (Saloranta, *et al*., 2006).

LDP are a threat to aquatic life and livestock. Tourism could be affected due to the death of wild life. Many animals ingest LDP, mistaking them for food, and therefore, die because it is indigestible. Ingested LDP remain intact even after the death and decomposition of the animal. Thus, it lies around in the landscape where another victim may ingest it and die.

When LDP are littered, they are carried by wind and rain storms and clog drainage and sewer lines. Water can thus not flow freely through the drainage systems. This is a common feature in our urban areas causing flooding.

The decomposition of LDP takes about 1000 years (Kenneth, 2011). This means LDP remains in the environment for a long period of time exacerbating the above effects. It is therefore, important to develop a method which can be used to convert LDP into useful products in order to protect environmental pollution.

1.6 Hypothesis

(H_0) Low density polyethylene cannot be converted into waterproofing agent for CSB’s.

1.7 Objectives

1.7.1 General Objective

To develop a method for converting low density polyethylene ‘LDP’ into waterproofing agent for cement soil blocks ‘CSB’s’.

1.7.2 Specific Objectives

1. Develop soil blocks enhanced with cement (CSB’s).
2. Formulate low density polyethylene (LDP) papers as waterproofing agent for CSB’s.
3. Establish the paint characteristics of the low density polyethylene (LDP) waterproofing agent.
4. Determine cost of the low density polyethylene (LDP) waterproofing agent.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Low Density Polyethylene Use

Low density polyethylene (LDP) represents about 25% of the materials used in packaging industry (Fitzgerald, 2008). It was estimated that between 500 billion and one trillion LDP bags were being used globally each year by 2004 and this amount is continuously increasing (Food Production Daily, 2004). In 2005, about 4,000 tons of LDP bags were being produced monthly in Kenya. Half of this amount went into the waste stream (UNEP, 2005).

2.2 Research on LDP Management

A. Thermal degradation of Low density polyethylene

The thermal degradation of Low density polyethylene (LDP) and high density polyethylene (HDP) waste was investigated in a horizontal tube reactor at temperatures of 500 ^{0}C, 525 ^{0}C and 550 ^{0}C (Miskolczi, *et al*., 2003). By thermal cracking, the HDP and LDP were converted into gas, liquid and wax-like hydrocarbon products with the yields of 3.1 – 6.0 %, 5.9 – 22.4 % and 70.6 – 91 % respectively (Miskolczi, *et al.*, 2003).

These fuel like products consisted of hydrocarbons of C_5 - C_{10} and C_{11} - C_{17} in case of lighter and heavier products respectively which might be used as feed stock materials. Differences in the properties of volatile products could be observed with increasing temperature, but no significant differences were noticed between various waste polymers. Subsequent distillation of the products, fuel like liquids that had low sulphur and nitrogen content and high cetane index was carried out. The gas and liquid products contained a significant amount of unsaturated hydrocarbons, mainly terminal olefins (Miskolczi, *et al.*, 2003).

B. Use of low density polyethylene in cement concrete pavement

Literature reports by (Kumar and Prakash, 2011) established the possibility of using LDP in cement concrete pavement. In order to establish the amount of cement and sand which could be replaced by LDP in concrete, varying amount of powdered LDP was added to coarse aggregates heated to a temperature of 800 ^{0}C. After cooling for three hours, they were mixed with cement, fine aggregates and water to prepare concrete mix which was casted into concrete cubes. Compressive strength of the cubes was established. These tests revealed that the optimum LDP content was 5% and the strength of the cubes was found to be two times greater than the plain cement concrete (Kumar and Prakash, 2011).

C. Decomposition of low density polyethylene through heating

Research has been conducted to decompose LDP into its elements by heating it past its point of melting in a sealed container that builds up pressure. When the chamber is filled with inert gas instead of air, the hydrogen in LDP becomes hydrogen gas. The carbon forms tiny carbon spheres which conduct heat and electricity (Vilas, 2010).

D. Use of low density polyethylene to shield solar flares

Experiments have been conducted with various mixtures of pulverized LDP and coal by injecting them into furnace under controlled conditions. By adding LDP into a molten iron melt at more than 1,500 ^{0}C, it has been shown that carbon from LDP can dissolve into iron (Veena, 2004). LDP - based material called RXF1 for protecting astronauts from deep-space radiation has been developed. It has 3 times the tensile strength of aluminum, yet is 2.6 times lighter. Aluminum, which provide adequate shielding in Earth orbit or for short trips to the Moon, would be inadequate for the trip to Mars. LDP is an appealing alternative compared to aluminum. LDP is 50% better at shielding solar flares and 15% better than aluminum for cosmic rays (Raj, *et al*, 2005).

E. Modification of asphalt using low density polyethylene

The use of LDP as a modifier in asphalt has been studied. In this research, LDP was used to investigate the potential prospects to enhance asphalt mixture properties. The objectives also include determining the best type of polyethylene to be used and its proportion. Marshall mix design was used, first to determine the optimum bitumen binder content and then further to test the modified mixture properties. The optimum asphalt content was 5.4%. The results indicated that grinded LDP modifier provides better engineering properties. The recommended proportion of the modifier is 12% by the weight of bitumen content. It was found to increase the stability, reduce the density and slightly increase the air voids and the voids of mineral aggregate. (Mohammad and Lina, 2007).

F. Converting ground tyre rubber using low density polyethylene

Research has been done to convert ground tyre rubber (GTR) by reactive blending with polyolefins into thermoplastic elastomers (TPE) of suitable mechanical and rheological properties. It has been established that bituminous reclamation of GTR prior to extrusion melt compounding with polyolefins is a promising way of TPE production. By this way the soluble content (acetone soluble fraction) of the GTR increases and the GTR particles can be better incorporated in the corresponding polyolefin matrix. The adhesion between GTR and matrix is given by molecular intermingling in the resulting interphase.

GTR particles of various production and mean particle size were involved in this study. As polyolefins recycled LDP, recycled HDP and polypropylene (PP) were selected. First, the optimum conditions for the GTR reclamation in bitumen were established (160 °C < T <180 °C; time ca. 4 hours). Polyolefin based TPEs were produced after GTR reclamation in extrusion compounding. Their mechanical (tensile behaviour, set properties), thermal (dynamic-mechanical thermal analysis, differential scanning calorimetry) and rheological properties (both in low- and high-shear rates) were determined.

The PE-based blends contained an ethylene/propylene/diene (EPDM) rubber as compatibilizer and their composition was as follows: PE/EPDM/GTR:bitumen = 50/25/25:25 The selected TPEs met the most important criterion, i.e. elongation at break > 100 %; compression set < 50%. The LDP-based TPE (TPE(LDP)) showed better mechanical performance compared to the TPE(HDP). This was assigned to the higher crystallinity of the HDP (Lievana, 2005).

G. Blending low density polyethylene with other plastics

Experiments have been conducted using post-consumer, mixed-color LDP, HDP, PP, PS, PET, and PVC which were processed in a bench-scale, 25-mm twin-screw extruder. Plastics were fed as individual components and as dry blends at various ratios. The final products were strongly affected by the cooling available for the extruder and by the intensity of shearing during the process. The products range from flakes (2 to 3 mm) and fluff (1 to 2 mm) to various particle-size powders, including ultrafine powders below 200 microns (Khait, 2011).

H. Co-firing low density polyethylene with coal

A study was conducted to investigate the effect of simultaneous co-firing of waste plastic with coal (Sushil, 2006). Two Australian coals, premixed with LDP and HDP, were combusted in a drop tube furnace at 1473 K under a range of combustion conditions. In all the tested conditions, most of the coal blends including up to 30% plastic indicated similar or marginally higher combustion efficiency compared to those of the constituent coals even though plastics were not completely combusted. In a size range up to 600 μm, the combustion efficiency of coal and polyethylene blends was found to be independent of the particle size of plastic used. Both LDP and HDP were shown to display similar influence on the combustion efficiency of coal blends.

The effect of plastic appeared to display greater improvement on the combustion efficiency of low volatile coal compared to that of a high volatile coal blend. The study further suggested that the effect of oxygen levels of the injected air in improving the combustion efficiency of a coal–plastic blend could be more effective under fuel rich conditions. The study demonstrates that waste plastic can be successfully co-injected with PCI without having any adverse effect on the combustion efficiency particularly under the tested conditions (Sushil, 2006).

I. Dissolving low density polyethylene into toluene

Low density polyethylene was dissolved into toluene at 500 ^{0}C over three different commercial fluid catalytic cracking (FCC) catalysts in a laboratory Riser Simulator Reactor. Short reaction-times up to 12 sec. were used. All the catalysts had qualitatively similar behaviors. The specific contribution of the polymer to the product slate of FCC was centered in hydrocarbons in the range of gasoline, with high aromatic content and highly olefinic $C_3 – C_4$ gases. Saturated $C_4 – C_5$ products were mainly iso-paraffins. The additional coke formed by the polymer would make coke yields to increase moderately in relation to the standard operation. These facts confirmed that this recycling option, which is based on a proven technology, represents an alternative to solve a major environmental problem (Sedran, *et al.*, 2002).

J. Converting low density polyethylene in to lubricating base oil form

A process has been developed for the conversion of waste plastic to lubricating base oil. It has also been demonstrated that waste plastic and fischer-tropsch (FT) wax can be co-processed to produce lube range molecules. The process uses a thermal, noncatalytic, atmospheric pressure pyrorysis process that converts high molecular weight molecules to lower molecular weight molecules in the lube oil range. Hydroisomerization is then used to convert this product to low pour point oils of unconventional base oil quality. The major byproduct is diesel, with little production of C_4 gas (Miller, *et al*., 2005).

K. Use of low density polyethylene to improve quality of shale oil

The pyrolysis experiments on oil shale mixed with LDP were carried out with the aid of thermogravimetric analyzer, differential scanning calorimetry system and distillation furnace (Yong, *et al*., 2011). The results obtained indicate that a synergistic effect exists to some extent during pyrolysis of oil shale mixed with LDP. The temperature of maximum degradation of the mixture is approximately 5 °C lower than that of oil shale. The difference in weight loss between the pure oil shale and that mixed with LDP is 1.17% at 550 °C. Co-pyrolysis experiments of oil shale mixed with LDP show an increased shale oil yield, and the obtained oil contains novel alkynes not occurring in shale oil or LDP oil. Co-pyrolysis improves the quality of shale oil (Yong, *et al*., 2011).

2.3 Paint and Painting

2.3.1 Paint

Paint is a material that is applied as a liquid and dries by a variety of chemical processes to a solid. It is applied for decoration, protection, identification or sanitation. Paint consists of pigment, resin, solvent and additives.

2.3.1.1 Pigments

Pigments are used to provide colour, hiding and to control gloss. Pigments are usually divided into two groups. One called ‘Prime Pigments’ includes pigments such as Titanium Dioxide (white), Chrome Green Oxide, Yellow and Red Iron Oxides, etc. The other group of pigments is called ‘Extender Pigments’ and includes Calcite (Calcium Carbonate), Talc (Magnesium Silicate), Mica, Barytes (Barium Sulphate), etc.

2.3.1.2 Resin

Resin is the binder which holds the pigment particles together and provide adhesion to the surface painted. Waterborne paints most often use acrylic emulsion polymers as binders. These come in a wide variety of types and combinations. Common acrylic polymer types are based on monomers such as methyl methacrylate and butyl methacrylate. Traditionally, lower cost paints have been formulated on poly vinyl acetate (PVA) binders.

Solvent based resins come in a very wide range of types. The most common solvent based resins are termed ‘alkyd resins’ that are normally used in enamel paints. Urethane alkyds are often used in clear varnishes. Protective coating resins include types such as Epoxy, Urethane, Polysiloxane and Moisture Cured Urethane.

2.3.1.3 Solvent

Solvent acts as a carrier for the pigments and resin. The solvent may be organic (such as Mineral Turps) or water.

2.3.1.4 Additives

Additives are used to enhance certain properties such as ease of brushing, mould resistance, scuff resistance, drying and sag resistance.

2.3.1.5 Manufacturing Process

The manufacturing process involves five critical parts:

Part 1 – Measurement of ingredients

Ingredients are measured calibrated vats and graduated measuring containers. Where greater accuracy of small additions is required highly accurate electronic scales are used.

Part 2 – Mill-base preparation and pigment dispersion

Pigments are powders of typically small size that tend to stick together to form by weight on scales, and in some cases by volume in clumps or agglomerates. These must be broken down into separate particles that must then be wetted by resin and additives to stop them sticking together again. This is the process of dispersion.

High speed mixers are used for combining materials and dispersing most pigments. These machines rotate stainless steel serrated discs of up to 60 cm diameter, at up to about 1000 rotations per minute. Pigments are added slowly to a portion of the liquid paint components, with the mixer running, to form the mill-base. Certain pigments are more difficult to disperse and require ball milling, bead milling or bar milling.

Ball mills are used for small batches of difficult to disperse mill-bases. Ball mills are large porcelain lined rotating drums containing golf ball sized porcelain balls. Rolling and tumbling of the balls provides sufficient force to break up agglomerates.

Bead mills are used for large batches and can maintain semi-continuous output. Operation is similar to a ball mill but the vessel is smaller and mixing is at a higher speed producing more rapid output.

Bar mills are especially useful for highly viscous (thick) mill-bases. The mill-base is forced through a small clearance between a rotating water cooled roller and a bar pushed against the roller.

Part 3 – Let-down

In a separate, larger, vat the rest of the paint (resin, solvent and additives) is combined and mixed. This is called the let-down. When the let-down and the mill-base are completed, the mill-base is added with stirring to the let-down. At this stage, if required by the formulation, any final additions are made and added in.

Part 4 – Finished product and in process laboratory testing

Product quality is monitored throughout the manufacturing process by the Product Verification Laboratory. Critical ingredients are tested before manufacturing starts. The mill-base may be tested for dispersion; if necessary further processing may be required. The let-down may be tested to ensure it is sufficiently mixed.

The completed batch (mill-base plus let-down and any final additions) is thoroughly tested by the Product Verification Laboratory. These final tests evaluate properties such as degree of dispersion, viscosity (consistency), density, hiding, tint strength and colour, application, dry time, gloss and dry film appearance.

Part 5 – Canning

When testing is completed the batch is passed for canning. During canning samples are taken; a retain sample, which is stored in case it is needed for future reference, and a final inspection sample. The final inspection sample is tested to guarantee conformance to relevant standards and specifications. After this final stage of testing is complete the batch is passed for storage in warehouse and dispatch to sale outlets.

2.3.1.6 How paint works

The simplest types of paint are lacquers that form a film by evaporation of solvent. Waterborne paints are usually based on emulsion resins. As the water in these paints evaporates the resin and pigment particles get closer and closer together until they begin to touch each other. When the resin particles touch each other and the pigments, they stick together and fuse into a tough elastic solid, which is recognised as the paint film.

Solvent borne enamel paints are based on alkyd resin dissolved in solvent (mineral turps). When the solvent evaporates the first stage is the formation of a tacky lacquer. The alkyd resin progressively reacts with oxygen from the atmosphere and polymerises to form a hard, tough coating.

Two component protective coating paints are unreactive on their own, but when mixed together undergo a chemical reaction. The chemical reaction takes a few hours (depending upon temperature) and results in an extremely tough, hard coating with great adhesion.

2.3.2 Painting

The oldest Mediterranean civilization, Greek, Roman and Egyptians extensively used painting techniques based on mixtures of encaustic, mineral pigments (iron, copper and manganese oxides) and tempera (Pioch, 2002). Vegetable oils, such as flax, walnut or poppy seed oil were known to ancient Egyptians, Greeks and Romans.

At the end of the Roman Empire and up to the Renaissance period (15th century), this ancient technique was lost and replaced by oil paint. In Italy and Greece, olive oil was used to prepare pigment mixtures but the drying time was excessively long and tedious. This drawback led a German monk, Theophilus , in the 12th century to warn against paint recipes including olive oil. It was reported that Aetius Amidenus , a medical writer in the 5th century, mentioned the use of a drying oil as a varnish on paintings. Similarly, it seems that perilla oil was used in Japan in painting after addition of lead in the 8th century (Eaton, 1981; Das, 1983; Pioch, 2002).

According to Pioch (2002) and Tibbets (1982) the technique of oil painting, as used till now with few technical modifications, was invented in Europe around 1410 by Jan van Eyck (1390 - 1441). After Van Eyck, Antonello da Messina (1430-1479) introduced a new technical improvement. He added a lead oxide (litharge) in the pigment-oil mixtures to increase their siccative property. Later, Leonardo da Vinci (1452-1519) improved the preparation in cooking the oily mixtures at low temperature (boiling water) after the addition of 5 to 10% of bee wax, thus preventing a too dark color (Tibbets, 1982; Pioch, 2002).

2.4 Cement Soil Blocks

2.4.1 Soil as a Building Material

Soil is one of the oldest building materials in the world. It is usually readily processed with only simple hand tools. The processed soil may be easily molded or compressed to form a building material which possesses good compressive strength, while it remains dry. As some form of soil covers virtually the whole land surface of the earth it is not surprising that soil has been traditionally used for construction in all but the wettest climates. The large scale use of soil in the past and its continued widespread availability as a raw material suggests that it will continue to be a significant building material for the foreseeable future (Gooding, 1994).

There are four types of traditional unstabilised soil walling which are known as; wattle and daub, cobb, sun-dried mud brick and rammed earth. In more recent times these materials have become stigmatised as being second rate and inferior to the more modem concrete and fired brick. The huge variation in soil types which exist within one country, let alone the world, has led to great difficulty in predicting the properties of soil-based building materials. The more modem materials are by contrast more predictable and hence are preferred by engineers and architects (Gooding, 1994).

Moreover traditional unstabilised-soil building methods result in structures which frequently have a short life or a high maintenance cost as a result of their low strength and poor dimensional stability. This experience with unstabilised soil structures has led to the association of soil with substandard or temporary buildings in the minds of many.

The prime drawback to building with earth is that its compressive strength is lost when it becomes wet; even highly compressed rammed earth will revert to mud if it is subjected to prolonged water saturation. The aim of the various soil stabilisation processes is twofold, to increase the wet strength of the wall such that even after prolonged saturation the wall will not collapse and to increase the wall's durability thereby reducing the maintenance cost and extending the building's life. With successful stabilisation, soil may be fully comparable with other types of walling material (Norton, 1997).

Historically in many countries any buildings which were considered to be of importance were built of brick or stone, both of these materials being substantially more durable and requiring much lower maintenance than soil. However with the emergence of Soil Mechanics (the scientific study of soil) in the 1930's it became possible to specify and select soils for building in terms of their properties. The particle grading, plasticity and organic or soluble salt level could be used to help predict the suitability of soils for certain construction uses (Kerali, 2001).

2.4.2 Soil for Making Cement Soil Blocks

2.4.2.1 General properties

Soil is the result of the transformation of the underlying rock under the influence of physical, chemical and biological proces. Material underneath this organic layer is much better as it usually contains a cross section of particle sizes and includes a proportion of small soil particles called “fines”. These are usually defined as particles passing a 75µm mesh and consist of silt and clay. Clay is necessary in CSBs production because it aids the workability of the mixture, increasing levels of consolidation and improving strength. Larger particles “sands” found in soil can generally be assessed as minerals that are silicas, silicates or limestones. Soil has a proportion of water and air that fill the gaps between adjoining particles in the soil. This gives natural soil a nonhomogenous and porous nature (Sjostrom, 1996).

Systems for identifying some major characteristics have been developed to define different ranges of soil characteristics. The most common of these is the size distribution of the soil particles. The physical characteristics that can define a sample of soil includes color, shape, apparent bulk density, specific bulk density, size or texture, moisture content, porosity or voids ratio, permeability, effective surface area, adhesion, specific heat capacity, dry strength and linear contraction. Chemical properties are also sometimes of interest particularly when a chemical additive is used. These chemical properties include the composition, mineral content, metallic oxides, pH levels and sulphates in the soil (Sjostrom, 1996).

Soil characteristics and climatic conditions of an area must be evaluated before manufacturing CSBs. A dry climate, for example, needs different CSBs from those used in temperate, rainy or tropical areas. All soils are not suitable for every building need. With so many different characteristics that one could discover about a sample of soil, it would be foolhardy to try and discover them all in every situation that soil is to be used for making CSBs. Only a small number of characteristics are of real relevance to the scientist testing the soil. The chemical composition of the soil is of little importance once the absence of unstable compounds and organic matter has been established (Matero and Bass, 1995).

The physical properties are of greater interest for making compressed CSBs as these will help to determine its ease of mixing, forming, de-moulding, porosity, permeability, shrinkage, dry strength and apparent bulk density. Controlling or monitoring the clay fraction is important in making compressed CSBs. Too much clay results in unacceptably high expansion upon wetting, requiring excessive amounts of cement to attune this. Too little clay causes low adhesion between particles and hence causes high breakage rates on de-moulding of the compressed CSBs. The basic material, however, required to manufacture CSBs is a soil containing a minimum quantity of silt and clay so as to facilitate cohesion (Jerome, 2000).

Optimum fines content for making compressed CSBs is suggested to be about 25% of which more than 10% is clay (Jerome, 2000). A more useful range of particle sizes suitable for building with CSBs is given in as follows (Kerali, 2001):

- Sand/fine gravel: 40 - 75%
- Silt: 10 - 30%
- Clay: 15 - 30%

The detrimental characteristic of expansion and contraction of a compressed CSB can only occur if three characteristics are present: “Clays” and “Porosity and Permeability” and “Moisture differential”. If any one of those is absent then expansion and contraction will not occur, (ignoring thermal expansion and contraction). We need clay to be present in compressed CSBs and it is impossible in humid climates to avoid moisture differentials so that the only characteristics that we can seek to reduce are the porosity and permeability (Kerali, 2001).

2.4.2.2 Classification of Soil

Soils are classified in many different ways: by their use, origin, size, texture, color and density. For building purpose soil can be generally characterized in two ways, by particle size distribution analysis and by a plasticity index. The particle size analysis will give information on the soil ability to pack into a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of cohesion of the fines (Atzeni, *et al.*, 1993).

A. Classification by Grain Size

All soils consist of disintegrated rock, decomposed organic matter and soluble mineral salts. Soil types are graded according to particle size using a system of classification widely used in civil engineering. The classification of soils based on grain size is pebbles (200 to 20mm), gravel (20 to 2 mm), sand (2 to 0.006mm), silt (0.006 to 0.002mm) and clay (less than 0.002mm) (Atzeni, *et al*., 1993).

Gravel is not usually used in CSBs production, as the large particle size may lead to a poor (rough) surface finish. A suitable soil will contain a mixture of sand, silt and clay sized particles. The properties of each of these three fractions influence the properties of CSBs. The value of a well-graded soil for CSBs is that such a distribution of particle sizes gives a dense structure with a low specific surface area.

A dense structure is important for several reasons. A densely packed arrangement will have a higher number of contacting particles, giving a better load-bearing skeleton. The number and size of the inter-particle voids will be reduced as will the number of linked voids, these will reduce the porosity of the soil and hence also its permeability, thereby reducing susceptibility to water penetration. As the interlocking calcium silicate matrix extends through the soil voids, a more compact void system requires less cement to provide a matrix of equal efficiency (Matero and Bass, 1995).

The upper and lower limit to the soil’s grading also need to be considered. A soil may be considered well graded with a uniform distribution of particles from fine silt to coarse sand (coarse soil). The coarse soil will have a lower specific surface area than the fine soil, as the same mass of soil will contain fewer and larger particles. From the above consideration of specific surface area, it might be concluded that the more coarse soil would produce strong blocks with lower cement content than that needed for the fine soil. This is however only the case when the blocks are kept within the mould to cure.

A coarse soil containing no fines (silt and clay) is non-plastic and will not have sufficient cohesion to retain its shape on ejection from the mould or to allow easy transportation to the curing area (Matero and Bass, 1995). The coarse soil could be considered to be a form of sand-cement containing large voids (a result of the lack of fines). Large voids would increase the porosity of the block and lead back to the common sand-cement problem of rapid drying before the cement has had time to adequately cure. Such a soil would be considered well graded but still be unsuitable for soil-cement block production.

Conversely a well-graded fine soil, containing little sand but high clay content, would have a high specific surface area and expansive behavior. The high clay content would give the soil cohesion and stability on ejection from the mould, but the high specific surface area would require a large amount of cement to provide reasonable particle coverage.

Thus, a suitable soil will be well graded but certain other limits should also be imposed: the largest particle size present should not be sufficiently large to cause a poor surface finish. Sufficient fines (silt and clay) should be present to allow handleability on demoulding but not enough to blind the small quantity of cement to be used (Matero and Bass, 1995).

B. Classification by plasticity

The silt and clay content of a soil are responsible for soil cohesion and it is these fines that provide the fresh CSBs with handleability until the initial set of the cement has occurred. The degree of cohesion provided to the CSBs is dependent both on the fines present and the degree of compaction used to form CSBs (Jerome, 2000).

A low-pressure moulding process will require higher fines content than a high pressure moulding process. This is because increased compaction will force the soil particles into more intimate contact, thus strengthening the fresh compact. However, the fines, in particular the clay fraction can also lead to blinding of the cement as a result of their high surface area. The approximate surface area of fine sand and medium silt are 0.023 and 0.23 square meters per gram, while for three major clay groups, kaolinite, illite and montmorillonite this increases to 10, 100 and 1000 square meters per gram respectively (Jerome, 2000).

The fines also affect the final cured block’s expansion on wetting. Clay usually exists in small agglomerations, which expand in three dimensions on wetting as water penetrates some of the numerous individual particle boundary fissures. The expansions of the clay fraction must be largely restrained by the calcium silicate matrix in order to minimize expansion and contracting of the cured block, on reported wetting and drying. Hence for durability the clay fraction should be as small as possible to allow the lowest cement content. It might be expected from the large difference between the specific surface areas of the three clay types mentioned above that different clays will have significantly differing expansions characteristics on wetting. This is the case, in general as the surface area of the clay fraction rises, so does the amount it will expand on wetting. As a result the type of clay as well as the quantity present will affect CSBs (Jerome, 2000).

The fine fraction can be seen to be helpful to the CSBs production process but to adversely affect the wet strength and durability of the final cured CSBs. The quantity and type of clay should therefore be considered important soil parameters. The quantity of fines may be measured by using one of the sedimentation tests, however the clay type present is very difficult to determine without highly complex tests. It is not necessary to know the clay type present but it is important to know the properties exhibited by the clay.

The Atterburg tests defining liquid limit, plastic limit and plasticity index are used to quantify the plasticity of the finer fraction of a soil (only particles less than 0.425 mm are tested). These tests measure the percentage water contents at which the soil passes from a liquid state to a plastic state (liquid limit) and from a plastic state to a solid state (plastic limit). The numerical difference between the liquid and plastic limit (the plasticity index) thus gives the range of water content over which the soil may be considered plastic. As plasticity is dependent on the soil cohesion, it has been found that this index reflects the cohesive characteristics of the soil. Furthermore as cohesion is largely dependent on the specific surface area of the fines, these plasticity limits also reflects the expansiveness of the soil. A soil with a low plasticity index will display low cohesion and usually low expansion on wetting, while a high index soil will display the reverse (Jerome, 2000).

2.4.2.3 Suitable Soil for Cement Soil Blocks

A suitable soil should not contain organic material or excessive soluble salts, which would interfere with the setting of the cement. Its sand fraction should be well graded to provide a densely packed load-bearing skeleton for the block and its largest size particle should be small enough to give a smooth surface finish. The fine fraction should be sufficient to provide enough cohesion to the fresh block to prevent damage on ejection and transportation from the mould. Too large fines content will either require large cement content for adequate stabilization or will reduce the durability and wet strength of the final cured block. The cohesion of CSB will depend on the compaction pressure used and the type as well as the quantity of clay present in the fines (Kerali, 2001).

2.4.3 Tests for Soils for Making Cement Soil Blocks

2.4.3.1 Types of tests

Prior to soil cement block production there are three main types of tests, which may be conducted: field tests, laboratory tests and trial production tests. Field tests can divide the soils in to two categories. These categories are suitable and unsuitable and if suitable in to potential high and low cement classes (Gooding, 1994).

Laboratory tests can be used to characterize the soils by particle size distribution, plasticity or other numerical measures for relation to the selection criteria and enable simple soil modification by blending. The laboratory tests are appropriate where medium or large- scale production is planned, where minimizing cement content is especially important or when soil cement block making is moving into a new area. Trial production tests can be carried out on manufactured blocks to check that the final block properties required (dry strength, wet strength and durability) can be achieved (Gooding, 1994).

2.4.3.2 Field tests

Field tests are for preliminary site surveying to identify if the soils are most likely suitable and so restrict the number of soils to be more rigorously assessed by laboratory tests or trial production. The tests will provide a rough idea of a soil's grading and plasticity and also indicate whether a soil contains significant organic matter, a majority of gravel, a majority of sand or a majority of fines. They may also be able to distinguish whether silt or clay is a more significant fraction of the fines. They are generally fairly easy to perform and often require little or no experimental equipment, making them very simple to implement.

Simple field tests which are performed to get an indication of the composition of the soil sample includes: smell test, nibble test, touch test, sedimentation test, adhesion test, washing test, linear shrinkage test, dry strength test, water retention test, consistency test and cohesion test (Gooding, 1994)

2.4.3.3 Laboratory tests

The laboratory tests establish numerical values for certain soil parameters, primarily the percentage distribution of the different sizes of soil particles present and the plasticity limits. These values are subsequently used to determine the best available soil or domination of soils. There are four main types of tests: The sieving test, sedimentation test, Atterburg limit test and compaction test.

The sieving tests separate the different size fractions of the soil into discrete parts thereby indicating the soil's particle grading. The silt and clay fraction are too small to particle grading. The silt and clay fractions are too small to be easily separated by sieving and as such are normally reported as a combined fraction (Norton, 1997). The larger particles may be separated into a number of size fractions, depending on the number of sieve sizes available.

The sedimentation tests if correctly conducted have the ability to separate the larger sand and gravel size fraction from the combined fines fraction and under favorable circumstance to further distinguish the combined fraction in to separate silt and clay fraction (Norton, 1997). However the simplest test, the glass-jar sedimentation test, is usually included under field tests because visual discrimination of the silt/clay boundary may not be possible. In this case the test can only be used to give an idea of the general relative proportions of sand and fines (Norton, 1997).

In its coarsest form the glass- jar sedimentation test provides no more information than a sieving test and although less accurate, it does not require any mass measurement. Further, although the sedimentation time is long the operator time required to conduct the test is less than that for a sieving test (Jerome, 2000).

The shrinkage test is a test of the soil's contraction on drying and gives a combined measure of the soils' particle grading, plasticity and clay type. It gives an overall idea of the soils behavior and suitability for stabilisation. The degree of contraction may be thought of as a measure of the expansive force, which the soil stabiliser will have to withstand when a manufactured block is exposed to water. The degree of contraction is then taken as a measure of the quantity of stabiliser required. The shrinkage test may be used as a straightforward method of determining a soil’s suitability for use where more complex testing is not possible or not justified for small- scale production. (Jerome, 2000).

2.4.4 Soil Stabilisation

There are several methods of soil stabilisation widely used to improve construction quality. Some of the major stabilisation techniques are described below.

2.4.4.1 Mechanical stabilization

Mechanical stabilisation involves compacting the soil by using a heavy weight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil. The main effects of compaction on the soil are to increase its strength and reduce its permeability. The degree of compaction possible, however, is affected greatly by the type of soil used, the moisture content during compaction and the compression effort applied. Best results can be obtained by mixing the correct proportions of sand and clay in a soil (Jafarzadeh and Burnham, 1992).

Improved levels of compaction have a significant effect on the CSBs compressive strength of the sample and on the effectiveness of the cement stabiliser added. If a compressed stabilized CSB could be compacted to a higher density, then for the same ultimate strength the cement content could be reduced (Jafarzadeh and Burnham, 1992).

2.4.4.2 Cement Stabilisation

Studies have shown that cement is a suitable stabiliser for use with soil in the production of compressed CSBs (Atzeni, *et al*., 1993). Cement is mainly composed of Lime and Silica, which react with each other and the other components in the mix when water is added. This reaction forms combinations of Tri-calcium silicate and Di-calcium (Atzeni, *et al*., 1993). The chemical reaction eventually generates a matrix of interlocking crystals that cover any inert filler and provide a high compressive strength and stability.

Cement is usually mixed with an aggregate to form concrete. The aggregate is usually inert filler that makes up the bulk of the material, and the cement coats the aggregate in the gaps (Atzeni, *et al*., 1993). The concrete industry has recognized that the achieved strength of concrete is highly dependent on the quantity of voids present in the mixture before curing. The presence of 5% air voids will reduce the strength of a concrete mix by about 30% and even 2% voids can result in a drop of strength of more than 10% compared to a sample with 0% voids present (Gooding, 1994). To aid the particle intimacy, different aggregate grades are mixed together giving a spectrum of particle sizes that reduces the quantity of air voids in the material.

The water used to mix the concrete plays an important role both in placing the material and in achieving strength. The quantity of water used is typically calculated using an appropriate water-cement ratio. Very low water-cement ratios yield a highly unworkable mixture and more water has to be added to form the mixture into the desired shape. Additional water is called the free-water content and is calculated from the Slump test.

This water does not form part of the chemical reaction and will eventually evaporate from the concrete leaving voids of air throughout the material (Gooding, 1994). In order to keep the free-water as low as possible concrete can be compacted or vibrated to aid workability and consolidation.

Portland cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type (Atzeni, *et al*., 1993).

The lime released during hydration of the cement reacts further with the clay fraction forming additional cementations bonds. Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive strength.

With respect to the general processes of cementation, penetration and binding mentioned above, many factors must be considered. Processes may also vary between different types of soils. Cement is considered a good stabiliser for granular soils but unsatisfactory for clays. Generally cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilisation is between 3% and 18% by weight according to soil type (Gooding, 1994).

Findings have shown that there is a relationship between linear shrinkage and cement content needed for stabilisations. Recommended cement to soil ratio for shrinkage below 15 mm is 1 : 18 parts, between 15 – 30 mm is 1 : 16 parts, between 30 – 45 mm is 1 : 14 parts and between 45 – 60 mm is 1 : 12 parts (Gooding, 1994).

2.4.4.3 Lime Stabilisation

One major alternative binder to cement is lime. By adding lime to the soil for stabilisation, four basic reactions occur: Cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions (Jerome, 2000). The pozzolanic reaction is the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds, which bind the soil particles together. Lime can also reduce the degree, to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability.

Lime is a suitable stabiliser for clay soils. Lime is cheaply available than Portland cement in Kenya. It is estimated that up to 40 % of cement used in building construction in masonry mortars could be saved through the use of lime and other lime associated binders. The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make (Jerome, 2000).

When lime is used as a stabiliser instead of cement, the quantity of stabiliser required will increase. However, research findings shows that such increment is not necessary if a sufficiently high compacting effort is applied on a high clay content soil. The reduction in the volume of air voids brings the lime and soil particles into closer contact and the stabilising reactions can take place more easily (Jerome, 2000).

2.4.4.4 Bitumen Stabilisation

There are two ways whereby bitumen can stabilise soil. The first way is a binding process that increases soil strength particularly in granular soils. Small amounts of bitumen (2 % to 6 %) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength (Matero and Bass, 1995).

The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilisation are sandy soils. Clays need large amounts for good results (Matero and Bass, 1995).

The main disadvantages of bituminous materials as stabilisers are:

- They are not a traditional building material in most developing countries,
- Bituminous materials are expensive to import,
- Preparation costs are high (heating, storing and mixing),
- Heat can have an adverse effect on their binding properties, particularly in hot countries.

2.4.4.5 Gypsum Stabilisation

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilizations used gypsum for building purposes, mainly for plasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low calcinations temperature (about 1/7th of that needed for cement and 1/5th of that needed for lime). Gypsum is a good stabiliser for sandy soils (Jafarzadeh and Burnham, 1992).

2.4.4.6 Pozzolanas Stabilisation

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilisation and construction needs. Pozzolanas are found in their natural state as volcanic ash or pumice or it can be man-made (Roth and Pavan, 1991).

2.4.4.7 Other Stabilisers

Traditionally, many stabilisers such as animal dung, ant hill materials, bird droppings, plant extracts and animal blood, have been used for the manufacture of compressed CSBs (Kerali, 2001). These waste materials consist of nitrogenous organic compounds, which help bind together soil grains. Chopped straw, grasses and natural organic fibers, although not active stabilisers, they are used as reinforcement materials to reduce linear shrinkage problems, which occur wih soil that has high clay content (Norton, 1997).

2.4.5 Rationale of Stabilising Soil with Cement

Soil on its own can be used for construction, but unless it is protected from water the resulting building will not be very durable in any but the driest climate (Lunt, 1980; Agarwal, 1981). Cementitious stabilisation in combination with densification gives soil both wet strength and erosion resistance. Densification or compaction reduces the soils permeability and enhances the secondary cementitious bonding mechanism (Spence and Cook, 1983). Portland cement is the most commonly used stabiliser. Lime and lime pozzolana stabilisation are growing in popularity because, unlike cement, lime may be produced economically by small scale batching kilns. However at present the quality of lime produced by such small-scale kilns is highly variable and liable to change from one batch to another (Webb, 1988).

Soil cement is produced by dry mixing a suitable soil with a small quantity of cement and remixing the product with a specific quantity of water. The resulting damp soil is compressed in a mould, ejected and subsequently wet cured for 3 - 4 days then damp cured for twenty-eight days before incorporation in a building. In many ways soil-cement may be seen as a simpler version of sand-cement, not requiring the sand to be first separated from other soil constituents. Sand- cement is widely used, though variable in quality as a result of poor curing. Soil cement blocks produced with compression are denser and hence less porous than sand cement. The resultant reduction of moisture loss during curing leads to a greater consistency in quality for soil cement (Sjostrom, 1996).

In the presence of damp soil, tricalcium silicate and dicalcium silicate in cement hydrate to form mono and dicalcium silicate hydrate gels. These gels then slowly crystallise into an insoluble interlocking matrix throughout the soil voids binding the soil particles together. As the matrix is insoluble it gives a strength mechanism that works to restrain the softening and swelling of the unaffected soil, thereby dramatically reducing the weakening effect of water (Sjostrom, 1996; ILO, 1987).

2.5 Materials and Equipment Used in this Research Work

2.5.1 Materials

When making the waterproofing agent, low density polyethylene (LDP), alkyd resin (Synald 1070w long oil alkyd), kerosene and red iron oxide were used. Red soil and ordinary portland cement were used for making Cement Soil Blocks (CSBs).

2.5.1.1 Low Density Polyethylene

LDP used had 0.30 N/mm^2 tensile strength, 65 ^0C thermal coefficient of expansion, 115 ^0C melting point and 0.925 g/cm^3 density. LDP has a high degree of short and long chain branching (Saechtling, 1987). It has less strong intermolecular forces as the instantaneous-dipole induced-dipole attraction is less. This results in a lower tensile strength and increased ductility. The high degree of branches with long chains gives molten LDP unique and desirable flow properties (Saechtling, 1987).

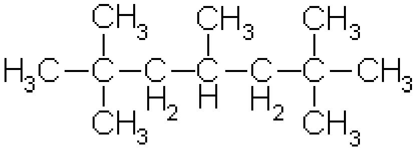
2.5.1.2 Long Drying Oil Alkyd Resin

Alkyd resins are manufactured from the condensation reaction between oil/polyols, acids, and alcohol. They are used as binders for coatings and printing inks. Long oil alkyd resins that contain high content of oil/polyols and modified alkyd resins undergo oxidation polymerization as air drying with the combined use of a dryer, and these are used in the coatings for industrial products.

Long drying oil alkyd resin used was clear viscous liquid free from suspended matters, 0.95 g/cm^3 density, 34 ^0C flashpoint and 100 KU viscosity. Long drying oil alkyd resins are prepared using unsaturated oils (Thomas, 2004; Standeven, 2003). They are soluble in aliphatic solvents. They have good brushing characteristics, dry rapidly in air and give reasonably durable, glossy films. Their drying process involves attack by oxygen in the unsaturated regions of the fatty acid residues followed by cross linking (Thomas, 2004; Standeven, 2003).

2.5.1.3 Kerosene

Kerosene has more than one chemical structure because it contains carbons from 12 carbons to 15 carbons. The molecular formulas can range from C12H26 to C15H32

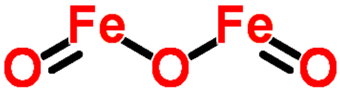


Kerosene structure

Kerosene used was colorless, had 0.80 g/cm^3 density, 50 °C flash point and 44 MJ/kg heating value. In coatings, kerosene is used as a solvent only when extremely low solvency and slow evaporation are desired. When used as a solvent in coatings, it improves the coating brushability and flow by slowing down the over-all evaporation (Potter and Simmons, 1998).

2.5.1.4 Red Iron Oxide

Iron oxides are produced from ferrous sulfate by heat soaking, removal of water, decomposition, washing, filtration, drying and grinding. They are produced in either anhydrous or hydrated forms. Their range of hues includes yellows, reds, browns and blacks.



Fe_2O_3 structure

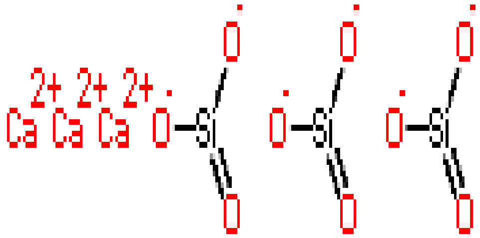
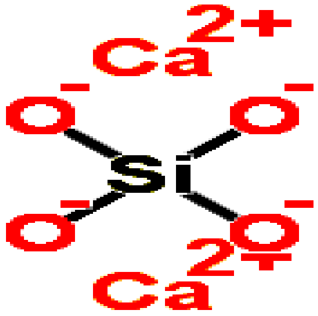
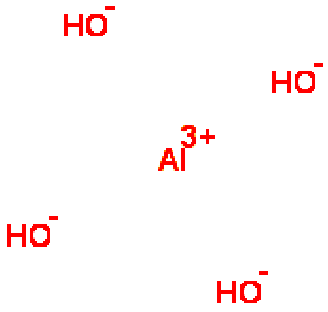
Red iron oxide used has a density of 0.9 g/cm^3, a melting point of 1566 °C, 0.3 % residue on 325 mesh and 95 % tinting strength. Natural red oxides such as hematite, are opaque, absolutely permanent and have excellent covering power. They do not react with solvents, and are indifferent to alkalis, but are partially soluble in acids. They are strong absorbers of ultraviolet (UV) light (Predd, 2007). Natural red iron oxide absorbs a moderate amount of oil (Janson, 2001). The oil absorption ratio is 18 parts by weight of pigment to 100 parts by weight of linseed oil (Jusko, 2009). It forms average drying oil coating and a hard, fairly flexible film (Gottsegen, 2007). Natural red iron oxide is not considered to be toxic (Johansen, 2006). It has a density of 5.27 g/cm^3 and its refractive index is 2.78 – 3.01 (Michael, 2007).

2.5.1.5 Cement

Bamburi Nguvu Pozzolanic Cement (NPC) and ARM Rhino Pozzolanic Portland Cement (RPC) were used. The composition and properties of these cements is shown in Table 2.1 and 2.2 below.

Table 2.1 Properties of Bamburi Nguvu Pozzolanic Cement

Properties	**Values**
2 Day compressive strength	≥10 MPa
28 Day compressive strength	≥42,5 MPa _ 62,5 MPa
Initial setting time	≥60 minutes
Soundness (expansion)	≤10,0 mm
Chemical Properties	
SO_3	≤3.5 %
Specific gravity	2.8 - 3.1
Melting point:	>1000 ^{o}C
Freezing point	None, solid
Viscosity	None, solid
pH	pH of wet cement 12 - 14

Chemical composition principal chemical constituents	
Tri-Calcium Silicate	 3CaO.SiO molecular structure
Di-Calcium Silicate	 2CaO.SiO molecular structure
Tri-Calcium Aluminate	 3CaO.Al O molecular structure

Source (Bamburi, 2006)

When water is added to cement, the following series of reactions occur:

- The tricalcium aluminate reacts with the gypsum in the presence of water to produce ettringite and heat:

  Tricalcium aluminate + gypsum + water ® ettringite + heat

  $C_3A + 3C\underline{S}H_2 + 26H$ ® $C_6AS_3H_{32}$, $D\ H = 207\ cal/g$

  Ettringite consists of long crystals that are only stable in a solution with gypsum. The compound does not contribute to the strength of the cement glue.

- The tricalcium silicate (alite) is hydrated to produce calcium silicate hydrates, lime and heat:

  Tricalcium silicate + water ® calcium silicate hydrate + lime + heat

  $2C_3S + 6H$ ® $C_3\underline{S_2}H_3 + 3CH$, $D\ H = 120\ cal/g$

  The CSH has a short-networked fiber structure which contributes greatly to the initial strength of the cement glue.

- Once all the gypsum is used up as per reaction (i), the ettringite becomes unstable and reacts with any remaining tricalcium aluminate to form monosulfate aluminate hydrate crystals:

Tricalcium aluminate + ettringite + water ® monosulfate aluminate hydrate

$2C_3A + 3\ C_6A\underline{S}_3H_{32} + 22H$ ® $3C_4ASH_{18}$,

The monosulfate crystals are only stable in a sulfate deficient solution. In the presence of sulfates, the crystals resort back into ettringite, whose crystals are two-and-a-half times the size of the monosulfate. It is this increase in size that causes cracking when cement is subjected to sulfate attack.
The belite (dicalcium silicate) also hydrates to form calcium silicate hydrates and heat:

Dicalcium silicates + water ® calcium silicate hydrate + lime

$C_2S + 4H$ ® $C_3\underline{S}_2H_3 + CH$, $D\ H = 62$ cal/g

Like in reaction (ii), the calcium silicate hydrates contribute to the strength of the cement paste. This reaction generates less heat and proceeds at a slower rate, meaning that the contribution of C_2S to the strength of the cement paste will be slow initially. This compound is however responsible for the long-term strength of portland cement concrete.

- The ferrite undergoes two progressive reactions with the gypsum:

- in the first of the reactions, the ettringite reacts with the gypsum and water to form ettringite, lime and alumina hydroxides, i.e.
  - *Ferrite + gypsum + water ® ettringite + ferric aluminum hydroxide + lime*
  - $C_4AF + 3C\underline{S}H_2 + 3H$ ® $C_6(A,F)\underline{S}_3H_{32} + (A,F)H_3 + CH$
- the ferrite further reacts with the ettringite formed above to produce garnets, i.e.
  - *Ferrite + ettringite + lime + water ® garnets*
  - $C_4AF + C_6(A,F)\underline{S}_3H_{32} + 2CH + 23H$ ® $3C_4(A,F)\underline{S}H_{18} + (A,F)H_3$

Hardened cement paste consists of the following:

- Ettringite - 15 to 20%
- Calcium silicate hydrates, CSH - 50 to 60%
- Calcium hydroxide (lime) - 20 to 25%
- Voids - 5 to 6% (in the form of capillary voids and entrapped and entrained air)

It can therefore be seen that each of the compounds in cement has a role to play in the hydration process (Mamlouk and Zaniewski, 1999).

Table 2.2 Properties of ARM Rhino Pozzolanic Portland Cement

Properties	**Values**
LOI	2.58
SiO_2	20.56
Al_2O_3	5.32
Fe_2O_3	2.95
CaO	62.35
MgO	1.56
SO_3	2.25
Insoluble residue	2.86
Cl^-	0.033
SETTING TIME IN MINUTES	
Initial setting time	132 Min
Final setting time	180 Min
Soundness	1.0mm
COMPRESSIVE STRENGTH	
2 days	23.05Mpa
7 days	36.23Mpa
28 days	44.46Mpa

Source (ARM, 1997)

2.5.2 Equipment

Interlocking stabilized soil block press, soil sieve, weighing balance, stop watch, round bottom flask, water bath, pipette, beaker, metal container of 250 mL with a tight fitting lid, spatula, bristle brush for paint (6 cm wide), burnished mild steel panels of (50 cm x 50 cm), gauge consisting of a block of hardened steel (175 mm long, 65 mm wide and 13 mm thick), scraper consisting of double edged steel blade (90 mm long, 40 mm wide and 6 mm thick), tin plate (75 mm in diameter), thin glass rod (100 mm in length), air oven capable of maintaining 105 ± 2 ^{0}C, black and white cryptometer, wet abrasion tester, thermometer, and hydrometer were utilized.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Development of CSB's for Use with the Waterproofing Agent

Two types of cements {Bamburi Nguvu Pozzolanic Cement (NPC) and ARM Rhino Pozzolanic Portland Cement (RPC)} from manufacturers, and red soil sample from Kanini farm in Juja were selected and prepared. Throughout the research, tap water supplied by JKUAT was used. To this effect the following test procedures were followed. The mix proportions were made based on literature recommendations.

The first series of mixes (5 in number) were conducted to compare the difference in compressive strength values with age, rate of strength development of the CSB's developed using NPC. They were made with 24 % of water and cement content of 4 %, 6 %, 8 %, 10 % and 12 % by weight of soil. The Mix proportions are given in Table 3.1 below.

Table 3.1 Mix proportions for the 1st series

Mix code	**Cement (%)**	**Water (%)**	**Soil (Kg)**
NPC4	4	24	100.45
NPC6	6	24	100.45
NPC8	8	24	100.45
NPC10	10	24	100.45
NPC12	12	24	100.45

The second series of mixes (5 in number) were conducted to compare the difference in compressive strength values with age, rate of strength development of the CSB’s developed using RPC. They were made with 24 % water and cement content of 4 %, 6 %, 8 %, and 10 % and 12 % by weight of soil. The Mix proportions are given in Table 3.2 below.

Table 3.2 Mix proportions for the 2nd series

Mix code	**Cement (%)**	**Water (%)**	**Soil (Kg)**
RPC4	4	24	100.45
RPC6	6	24	100.45
RPC8	8	24	100.45
RPC10	10	24	100.45
RPC12	12	24	100.45

The third series of mixes (4 in number) were conducted to compare the effects of mould pressure on the compressive strength of the sample and on the effectiveness of the cement stabiliser. They were made with 4 MPa, 6 MPa, 8 MPa and 10 MPa pressure mould and cement contents of 6 %, 8%, 10 % and 12 % by weight of soil. The mix proportions are given in Table 3.3 below.

Table 3.3 Mix proportions for the 3rd series

Mix code	**Cement (%)**	**Mould pressure (MPa)**
C6P4	6	4
C6P6	6	6
C6P8	6	8
C6P10	6	10
C8P4	8	4
C8P6	8	6
C8P8	8	8
C8P10	10	10
C10P4	10	4
C10P6	10	6
C10P8	10	8
C108P10	10	10
C12P4	12	4
C12P6	12	6
C12P8	12	8
C12P10	12	10

3.2 Specimen Preparation

Literature indicates that an ideal soil would have an optimum raw materials composition of: sand 75 %, fines (silt and clay) 25 %, at least not less than 10 % has to be clay (Rigassi, 1995). The actual mix then used consisted of: Sand 70 %, Silt 16.25 % and Clay 13.75 %. A shrinkage test and a sedimentation test as recommended by Rigassi (1995) were used to confirm the limits for the different constituents. Proportioning the mix of the soil raw material with the cement stabiliser was done in varying quantities, by percent weight of cement from 4 % by weight in 2 % increments up to 12 % by weight of the soil as follows: 4 %, 6 %, 8 %, 10 % and 12 %. A total of two hundred four blocks of average dimension 220 x 220 x 115 mm were subsequently made in this manner for three series of tests.

The constituent parts of the mixed soil preparations were separately weighed using an electronic weighing machine. To produce the blocks, a compressing machine was used for the entire samples. Before filling the mould for each compression, the mould lining was lightly oiled with used engine oil. The soil was carefully poured into the mould, all pre-weighed, packed and sealed in light transparent plastic bags. After each pouring, the soil was leveled in the mould. The use of the machine was based on its operational manual.

The blocks were compressed by the compaction action of the machine up to 10 MPa. The mould cover was then moved upwards to expose the green block, which was, then demoulded. The green blocks were then carefully removed and put over base plates, and immediately placed in plastic bags and left to cure in the shade. The dimensions and the weights of the green blocks were recorded.

Curing of the blocks consisted of two distinct phases described herein as primary and secondary phases. The curing time, temperature, duration, and moisture conditions were of particular interest to the experiment. Primary curing, whose purpose is to ensure that moisture is retained in the block, and not lost rapidly, was done for a period of five days.

Laboratory dry conditions were used with curing temperatures of 22 - 24 °C. After five days, the blocks were noticeably lighter in color than when demoulded. Each of the blocks were marked using permanent ink markers in each case to clearly show the percentage cement content, moulding pressure, date and time of production, and an identification number. In order to enable the blocks to further achieve strength, secondary curing was allowed to continue for a further fifty-one days. The clearly marked blocks were placed side by side and covered with a large polyethylene sheet. This was done to slow down evaporation and to protect the blocks from external interference. The blocks were then left to dry in this manner under laboratory air conditions.

3.3 Tests on Cement Soil Blocks

Different separate tests and experiments, all of which have direct bearing with the effects of stabilisation and moulding pressure on the strength and performance of blocks, were selected and conducted. The tests include the wet and dry compressive strength tests and the water absorption test.

The compressive strength of the blocks is perhaps their most important property. The compressive strength values give an overall picture of the quality of the block and are an indication of the hardness of the hydrated cement paste that binds the various particles together. The main aim of the compressive strength tests was to determine the wet compressive strength values of the blocks. It is the wet compressive strength value, which is normally lower than the dry compressive strength, which is used in the structural design of buildings (Rigassi, 1995).

After the 7, 14, 28 and 56 days curing period, the blocks of average dimension 22 × 22 × 11 cm were measured and weighed. The main compression equipment used was the Concrete Testing Machine. Three blocks in each category of varying cement content from 4 % in increments of 2 % up to 12 % were tested for wet compressive strength.

Each block sample of dimension 22 × 22 × 11 cm was soaked for 24 hours in tap water at room temperature. They were then removed and kept aside for 30 minutes to let the extra surface water to drip off. The samples were then carefully placed within the set marking pins of the compression-testing machine.

The crushing load was then continuously applied without shock to the sample at a rate of 3.5 MPa per minute till failure (Rigassi, 1995), and in this way the maximum crushing load was obtained for each sample. The wet compressive strength was then calculated in each case from the ratio of the maximum load and the cross sectional area of the block in N/mm^2.

3.4 Water Absorption Test

The aim of the water absorption test was to determine the percentage moisture absorption capacity of the block samples. Block samples were weighed in the laboratory dry condition (Wd) and, immersed in water for 24 hours, removed and weighed again (Ww). An electronic weighing machine was used. The percentage moisture absorption by weight was calculated from the formula:

$$Mc = \frac{Ww - Wd}{Wd} \times 100\ (\%)$$

Where:

-Mc = percentage moisture absorption (%)

-Ww = mass of wetted sample (g)

-Wd = mass of dry sample (g)

Through the water absorption test, it should be possible to determine the ability and extent to which blocks can absorb moisture. Knowledge of the water absorption levels of blocks could serve as useful criteria for setting limits and for investigating possible ways of reducing the same in order to improve on the durability of blocks.

The apparatus consisted of a weighing balance, a stop watch and a water trough with a capacity to hold up to 2 fully immersed blocks. The entire test took two days to complete mainly due to the overnight soaking of the block samples in water. This test helped to investigate the effect of water absorption of CSBs during the rainy season. The recommended maximum water absorption value of blocks is from 15 % to the maximum value of 20 % (Rigassi, 1995).

3.5 Establishing Behavior of LDP Melt on Cooling

LDP was shredded and heated until it liquefied at 115 ^{0}C. The LDP melt was poured into a container, covered and left to cool at room temperature for 24 hrs and then observations were made.

3.6 Application of LDP Melt on CSB's

CBS's cured for 7 and 28 days respectively were immersed into hot LDP melt for 2, 4, 6, 8, and 10 min. They were allowed to cool to room temperature and observations were made and recorded. This was done to establish whether LDP melt could attach better in CSB's semi cured for 7 days or in CSB's cured for 28 days while varying the duration of immersion.

3.7 Improving LDP Melt for Waterproofing Agent Development

The LDP melt solidified after cooling to room temperature for 24 hrs. It therefore, required improvement in order to stop the solidification. This would allow the melt to be further improved into a waterproofing agent which could be stored for long and applied using paint brush.

3.7.1 Dilution of LDP Melt using Kerosene

In order to improve the LDP melt to a waterproofing agent, varying amounts of kerosene were added to it until the melt was a liquid at room temperature. Kerosene which was at room temperature was added to the LDP melt at 115 ^{0}C. The best ratio of LDP : Kerosene was established to be 1 : 2 (v/v). However, this melt had some solids which could not dissolve even by increasing amount of kerosene. Kerosene was added to the melt (LDP : Kerosene, 1 : 2 v/v) at varied temperatures. At 210 ^{0}C, the LDP : Kerosene melt produced a liquid melt which had no solid suspensions on cooling to room temperature.

3.7.2 Properties of the Improved LDP Melt when Applied on CSB's

The results from the activities undertaken in Section 3.6.1 provided a method for stopping solidification of the LDP melt on cooling. Using a paint brush, the improved LDP melt while at room temperature was applied on CSB's and its drying behavior monitored.

3.7.3 Slowing Down Drying Speed of the Improved LDP melt

The results from the activities undertaken in Section 3.6.2 indicated the need to further improve the LDP melt to slow down its drying speed which caused cracking and peeling of its dry film. Varying amounts of alkyd resin (Synald 1070w long oil alkyd) were added to the LDP melt and observations made. It was established that the best ratio which arrested cracking and peeling of the dry film was 1 : 1 (v/v).

3.7.4 Increasing Covering Power of the Improved LDP Melt Dry Film

Varying amounts of red iron oxide were added to the improved LDP melt developed during activities undertaken in Section 3.6.3 in order to establish the best ratio. It was established that adding red iron oxide to the improved LDP melt at the ratio of 1 : 0.2 {m/m} (LDP : Red iron oxide) gave the best covering power. The resulting melt was the desired waterproofing agent.

3.7.5 Kenya Standard Paint Tests on the Developed Waterproofing Agent

The waterproofing agent was subjected to the following tests:

3.7.5.1 Examination of Skin Formation According to Kenya Standard (KEBS 03 - 910, 1991)

The waterproofing agent was stirred with automatic spatula at the rate of 10 oscillations per min. and 130 ml poured into the metallic container. The lid was placed on tightly and the container was inverted to seal the lid. As required by KEBS 03-910 (1991), the waterproofing agent was allowed to stand upright for 7 days, opened and the surface of the waterproofing agent in the container tested with a spatula for any skin formation. The walls and the lid were examined for the presence of the skin. Observations were made at a temperature of 23 ± 2 ^{0}C and at a relative humidity of 65 ± 2%.

3.7.5.2 Brushing Properties Test According to Kenya Standard (KEBS 03-909, 1991)

The waterproofing agent was applied using a brush to the test panel by criss-cross strokes across a section of the test panel. The next section was coated in the same manner and this procedure was repeated until three quarters of the panel was covered as evenly as practicable. The film was allowed to dry for 24 hrs and the areas of lapping and that adjacent were examined for differences in gloss and other defects. Observations were made at a temperature of 23 ± 2 ^{0}C and at a relative humidity of 23 ± 2%.

3.7.5.3. Determination of Solid Content According to Kenya Standard (KEBS 03-910,1991)

The glass, tin plate and the glass rod in the oven were dried at 105 ± 2 ^{0}C and allowed to cool to room temperature in a desiccator. The dish containing the glass rod was weighed to the nearest milligram and then weighed into the dish, to the same accuracy, approximately 2 ± 0.2 g of the waterproofing agent, making sure it was evenly distributed over the surface of the dish.

The dish with the rod and the test portion was placed in the oven previously adjusted at 105 ± 2 ^{0}C and was left in the oven at this temperature for 3 hrs After twenty minutes of heating, the dish was removed from the oven, the waterproofing agent was stirred with the glass rod to break up any surface skin, the dish and the rod were then replaced in the oven.

The dish and the rod were transferred to a desiccator after heating them for 3 hrs They were allowed to cool to room temperature and reweighed to the nearest milligram. Two determinations on the same prepared waterproofing agent sample were performed.

The content of non-volatile matter (NV) was calculated as a percentage by mass of the sample waterproofing agent tested using the following formula;

$NV = 100 (M_2 /M_{1)}$

Where:

M_1 = The mass in milligrams of the waterproofing agent sample before heating

M_2 = The mass in milligrams of the waterproofing agent sample after heating under the specified conditions

3.7.5.4 Opacity Test According to Kenya Standard (KEBS 03-910, 1991)

The opacity of the waterproofing agent was determined using a black and white cryptometer. From the cryptometer, K = .004 top plate was selected. A blob of the waterproofing agent was placed in the center of the base plate close to the black / white division. The top plate was placed over the waterproofing agent with the supports on the black area of the tile. The top plate was pressed down firmly so that the waterproofing agent was spread without air bubbles to form a shallow wedge between the plates. This wedge moved with the top plate, the position of which was adjusted until it was observed that the black/white division was just obliterated. The scale reading was then noted from the white scale where the edge of the top plate made contact with the base plate.

The thickness of the waterproofing agent in millimeters over the black and white cryptometer division was obtained by multiplying the scale reading times the wedge constant K = 0.004 of the top plate used. This figure gave the minimum film thickness necessary to obliterate over black and white.

3.7.5.5 Drying Time Test According to Kenya Standard (KEBS 03-910, 1991)

Both the surface and hard drying of the waterproofing agent were determined using a drying time recorder.

3.7.5.6 Determination of Resistance to Washing According to Kenya Standard (KEBS03 -811, 1997)

A glass panel measuring 415 mm x 120 mm was cleaned. A coat of the undercoating enamel was applied to give a wet film thickness of 35 µm and stored at 120 ^{0}C for 30 min. It was then rubbed down and wiped using an emery paper until the gloss was removed completely. A coat of the waterproofing agent was applied to give a wet film thickness of 150 µm and allowed to air dry for 168 hrs.

The brush was dipped in distilled water at 25 ^{0}C for 30 min. to a depth of 12 mm. It was shaken to remove excess water and then soaked in the soap solution for 5 min. The coated test panel was fixed in the tray with coated surface upwards. The brush was fixed in its holder, having a total load of 0.5 kg. The stroke was then adjusted in such a way that not less than 10 mm of the film was left free on both ends before the oscillations of the brush were started.

The panel was kept wet by adding soap solution at the rate of 10 drops per min. in the path of the brush. The panel was then washed with water, allowed to dry and the film examined for any defects.

3.7.5.7 Determination of the Waterproofing Agent to Protect CSB’s

Twenty CSB’s were randomly selected and weighed after curing for 28 days. Ten were coated with the waterproofing agent. They were allowed to air dry for 168 hrs Both the coated and uncoated CSB’s were immersed in water troughs with clean water at room temperature. The water density and temperature and the CSB’s mass were monitored after every 24 hrs for 30 days.

3.8 Cost of the Waterproofing Agent

The following experiments were carried out to investigate the compromise between improving opacity and increasing formulation costs of the waterproofing agent (LDP : Kerosene : Resin : Red iron oxide 1 : 2 : 3: 0.2 m/m). Ten waterproofing agent series (each with four replications) were made using constant amounts (by weight) of red iron oxide per liter while varying the solvent and resin contents. The red iron oxide was set at 200 g/l.

These paints were applied to polyester film and their optical properties measured. The scattering coefficient for a 25µm dry film and the hiding power for a film resulting from 100µm wet paint were calculated using Kubelka-Munk equations (Michael, 2012).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1.1 Compressive Strength of CSB’s

There are several manufacturing variables that could affect the performance of CSB’s. These include soil type, cement content, compaction pressure, moisture content, and curing method. In the experiments conducted it was decided that of these several variables, only the cement content and compaction pressure would be varied while all the other parameters would remain fixed. The reason for this decision and approach was based on the fact that it was the stabiliser content and compaction pressure which, according to the literature on stabilised soils, were significantly responsible for the improvement in strength, dimensional stability and durability of CSB’s.

The 7th, 14 th, 28 th and 56 th days compressive strength values of CSB’s stabilised with Bamburi Nguvu Pozzolanic Cement (NPC) and ARM Rhino Pozzolanic Portland Cement (RPC) contents of 4 %, 6 %, 8 %, 10 % and 12 % are shown in Tables 4.1.1.A to 4.2.5.E

Table 4.1.1.A. CSB's Compressive Strength Tests Results using 4 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	16/7/2007	7	20.3×22.1×11.6	1844.7	0.3	0.3
2	9/7/2007	16/7/2007	7	20.7×22.1×11.6	1771.36	0.2	
3	9/7/2007	16/7/2007	7	20.4×22.1×11.6	1845.23	0.3	

Table 4.1.1.B. CSB's Compressive Strength Tests Results using 4 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	23/7/2007	14	20.3×22.1×11.6	1806.27	0.5	0.6
2	9/7/2007	23/7/2007	14	20.4×22.1×11.6	1816.53	0.6	
3	9/7/2007	23/7/2007	14	20.3×22.1×11.6	1810.41	0.6	

Table 4.1.1.C. CSB's Compressive Strength Tests Results using 4 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	20.6×22.1×11.6	1761.00	0.8	1.0
2	9/7/2007	6/8/2007	28	20.5×22.1×11.6	1769.60	1.0	
3	9/7/2007	6/8/2007	28	20.6×22.1×11.6	1761.00	1.0	

Table 4.1.1.D. CSB's Compressive Strength Tests Results using 4 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	3/9/2007	56	21×22.1×11.6	1690.3	1.2	1.25
2	9/7/2007	3/9/2007	56	21×22.1×11.6	1708.9	1.3	
3	9/7/2007	3/9/2007	56	21.2×22.1×11.6	1711.18	1.2	

Table 4.1.2.A. CSB's Compressive Strength Tests Results using 6 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	16/7/2007	7	20.5×22.1×11.6	1864.76	0.5	0.6
2	9/7/2007	16/7/2007	7	20.9×22.1×11.6	1866.39	0.6	
3	9/7/2007	16/7/2007	7	21.2×22.1×11.6	1867.56	0.7	

Table 4.1.2.B. CSB's Compressive Strength Tests Results using 6 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	23/7/2007	14	21.8×22.1×11.6	1837.86	1.2	1.3
2	9/7/2007	23/7/2007	14	20.3×22.1×11.6	1844.69	1.4	
3	9/7/2007	23/7/2007	14	21.1×22.1×11.6	1839.12	1.4	

Table 4.1.2.C. CSB’s Compressive Strength Tests Results using 6 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	20.7×22.1×11.6	1790.20	1.5	1.5
2	9/7/2007	6/8/2007	28	21×22.1×11.6	1801.8	1.5	
3	9/7/2007	6/8/2007	28	20.9×22.1×11.6	1791.7	1.4	

Table 4.1.2.D. CSB’s Compressive Strength Tests Results using 6 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	3/9/2007	56	20.8×22.1×11.6	1762.85	2.3	2.23
2	9/7/2007	3/9/2007	56	20.5×22.1×11.6	1769.62	2.1	
3	9/7/2007	3/9/2007	56	20.3×22.1×11.6	1748.62	2.3	

Table 4.1.3.A. CSB's Compressive Strength Tests Results using 8 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	16/7/2007	7	20.4×22.1×11.6	1873.9	1	1.1
2	9/7/2007	16/7/2007	7	20.9×22.1×11.6	1885.06	1.1	
3	9/7/2007	16/7/2007	7	20.2×22.1×11.6	1870	1.2	

Table 4.1.3.B. CSB's Compressive Strength Tests Results using 8 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	23/7/2007	14	21.3×22.1×11.6	1831.34	1.7	1.8
2	9/7/2007	23/7/2007	14	20.7×22.1×11.6	1846.74	1.8	
3	9/7/2007	23/7/2007	14	21.9×22.1×11.6	1828.74	1.8	

Table 4.1.3.C. CSB’s Compressive Strength Tests Results using 8 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.1×22.1×11.6	1793.20	2.0	2.1
2	9/7/2007	6/8/2007	28	21.1×22.1×11.6	1793.20	2.1	
3	9/7/2007	6/8/2007	28	20.6×22.1×11.6	1780.00	2.2	

Table 4.1.3.D. CSB’s Compressive Strength Tests Results using 8 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	3/9/2007	56	21.1×22.1×11.6	1756.27	3.2	3.2
2	9/7/2007	3/9/2007	56	21.1×22.1×11.6	1756.27	3.1	
3	9/7/2007	3/9/2007	56	20.9×22.1×11.6	1754.41	3.3	

Table 4.1.4.A. CSB's Compressive Strength Tests Results using 10 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	16/7/2007	7	20.7×22.1×11.6	1846.74	1.3	1.4
2	9/7/2007	16/7/2007	7	20.4×22.1×11.6	1931.26	1.4	
3	9/7/2007	16/7/2007	7	20.3×22.1×11.6	1876.94	1.4	

Table 4.1.4.B. CSB's Compressive Strength Tests Results using 10 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	23/7/2007	14	21×22.1×11.6	1857.51	2	2.1
2	9/7/2007	23/7/2007	14	21.1×22.1×11.6	1848.7	1.9	
3	9/7/2007	23/7/2007	14	21.8×22.1×11.6	1839.7	2.2	

Table 4.1.4.C. CSB's Compressive Strength Tests Results using 10 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	20.6×22.1×11.6	1836.8	2.5	2.6
2	9/7/2007	6/8/2007	28	20.6×22.1×11.6	1836.8	2.7	
3	9/7/2007	6/8/2007	28	21×22.1×11.6	1838.9	2.6	

Table 4.1.4.D. CSB's Compressive Strength Tests Results using 10 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	3/9/2007	56	20.2×22.1×11.6	1795.9	4.1	4.03
2	9/7/2007	3/9/2007	56	20.7×22.1×11.6	1771.36	3.8	
3	9/7/2007	3/9/2007	56	20.7×22.1×11.6	1771.36	4.2	

Table 4.1.5.A. CSB's Compressive Strength Tests Results using 12 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	16/7/2007	7	21.9×22.1×11.6	1888.04	1.4	1.5
2	9/7/2007	16/7/2007	7	21.7×22.1×11.6	1869.49	1.5	
3	9/7/2007	16/7/2007	7	21.1×22.1×11.6	1899.47	1.5	

Table 4.1.5.B. CSB's Compressive Strength Tests Results using 12 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	23/7/2007	14	22.3×22.1×11.6	1806.27	2.5	2.5
2	9/7/2007	23/7/2007	14	23×22.1×11.6	1841.7	2.5	
3	9/7/2007	23/7/2007	14	22.8×22.1×11.6	1818.22	2.6	

Table 4.1.5.C. CSB's Compressive Strength Tests Results using 12 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.8×22.1×11.6	1807.2	3.3	3.5
2	9/7/2007	6/8/2007	28	22×22.1×11.6	1808.5	3.5	
3	9/7/2007	6/8/2007	28	21.7×22.1×11.6	1797.6	3.5	

Table 4.1.5.D. CSB's Compressive Strength Tests Results using 12 % NPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	3/9/2007	56	22.1×22.1×11.6	1729.75	4.5	5.03
2	9/7/2007	3/9/2007	56	22.2×22.1×11.6	1765.05	5.3	
3	9/7/2007	3/9/2007	56	22.4×22.1×11.6	1758.83	5.3	

Table 4.1.5.E Mean Compressive Strength of CSB's using NPC

Mix code	Mean compressive strength [MPa]			
	7 days	14 days	28 days	56 days
NPC4	0.3	0.6	1	1.25
NPC6	0.6	1.3	1.5	2.23
NPC8	1.1	1.8	2.1	3.2
NPC10	1.4	2.1	2.6	4.03
NPC12	1.5	2.5	3.5	5.03

- **Compressive Strength Test Results Using RPC**

Table 4.2.1.A. CSB's Compressive Strength Tests Results using 4 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	2/7/2007	7	19.6×22.1×11.6	1880.73	0.1	0.15
2	25/6/2007	2/7/2007	7	20.6×22.1×11.6	1846.23	0.2	
3	25/6/2007	2/7/2007	7	20.2×22.1×11.6	1861.71	0.1	

Table 4.2.1.B. CSB’s Compressive Strength Tests Results using 4 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	9/7/2007	14	20.1×22.1×11.6	1814.53	0.8	0.7
2	25/6/2007	9/7/2007	14	20.3×22.1×11.6	1806.27	0.7	
3	25/6/2007	9/7/2007	14	20.8×22.1×11.6	1800.76	0.7	

Table 4.2.1.C. CSB’s Compressive Strength Tests Results using 4 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	23/7/2007	28	19.5×22.1×11.6	1720.34	0.6	0.8
2	25/6/2007	23/7/2007	28	19.9×22.1×11.6	1705.36	0.8	
3	25/6/2007	23/7/2007	28	20.4×22.1×11.6	1682.68	0.9	

Table 4.2.1.D. CSB's Compressive Strength Tests Results using 4 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	20/8/2007	56	20.4×22.1×11.6	1606.2	1.0	1.0
2	25/6/07	20/8/2007	56	19.5×22.1×11.6	1600.32	1.0	
3	25/6/07	20/8/2007	56	20×22.1×11.6	1638.3	0.9	

Table 4.2.2.A. CSB's Compressive Strength Tests Results using 6 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	2/7/2007	7	20×22.1×11.6	1852.86	0.33	0.4
2	25/6/2007	2/7/2007	7	20.7×22.1×11.6	1856.16	0.4	
3	25/6/2007	2/7/2007	7	20.2×22.1×11.6	1854.49	0.35	

Table 4.2.2.B. CSB’s Compressive Strength Tests Results using 6 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	9/7/2007	14	20.5×22.1×11.6	1826.7	1	1.0
2	25/6/2007	9/7/2007	14	20.6×22.1×11.6	1817.83	1	
3	25/6/2007	9/7/2007	14	20.3×22.1×11.6	1827.9	1	

Table 4.2.2.C. CSB’s Compressive Strength Tests Results using 6 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	23/7/2007	28	20.8×22.1×11.6	1725.34	1.5	1.6
2	25/6/07	23/7/2007	28	20.1×22.1×11.6	1766.02	1.5	
3	25/6/07	23/7/2007	28	19.9×22.1×11.6	1783.77	1.6	

Table 4.2.2.D. CSB’s Compressive Strength Tests Results using 6 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	20/8/2007	56	20.0×22.1×11.6	1638.32	1.7	1.85
2	25/6/07	20/8/2007	56	20.2×22.1×11.6	1660.72	1.8	
3	25/6/07	20/8/2007	56	20.1×22.1×11.6	1649.58	2.0	

Table 4.2.3.A. CSB’s Compressive Strength Tests Results using 8 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	2/7/2007	7	20.2×22.1×11.6	1852.86	0.8	1.0
2	25/6/2007	2/7/2007	7	20.5×22.1×11.6	1856.16	1.0	
3	25/6/2007	2/7/2007	7	20.1×22.1×11.6	1853.95	1.0	

Table 4.2.3.B. CSB’s Compressive Strength Tests Results using 8 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/2007	9/7/2007	14	19.9×22.1×11.6	1842.57	1.2	1.3
2	25/6/2007	9/7/2007	14	20.6×22.1×11.6	1836.77	1.2	
3	25/6/2007	9/7/2007	14	20.9×22.1×11.6	1829.07	1.4	

Table 4.2.3.C. CSB’s Compressive Strength Tests Results using 8 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	23/7/2007	28	21.2×22.1×11.6	1784.78	2.3	2.3
2	25/6/07	23/7/2007	28	20.5×22.1×11.6	1769.62	2.5	
3	25/6/07	23/7/2007	28	20.5×22.1×11.6	1769.62	2	

Table 4.2.3.D. CSB’s Compressive Strength Tests Results using 8 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	20/8/2007	56	20.3×22.1×11.6	1671.76	2.7	2.7
2	25/6/07	20/8/2007	56	20.2×22.1×11.6	1699.35	2.8	
3	25/6/07	20/8/2007	56	20.3×22.1×11.6	1690.97	2.7	

Table 4.2.4.A. CSB’s Compressive Strength Tests Results using 10 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	2/7/2007	7	21.5×22.1×11.6	1886.88	1.2	1.3
2	25/6/07	2/7/2007	7	20.8×22.1×11.6	1856.61	1.4	
3	25/6/07	2/7/2007	7	21.1×22.1×11.6	1879.26	1.2	

Table 4.2.4.B. CSB’s Compressive Strength Tests Results using 10 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	9/7/2007	14	22×22.1×11.6	1826.27	2	1.7
2	25/6/07	9/7/2007	14	21.6×22.1×11.6	1823.97	1.6	
3	25/6/07	9/7/2007	14	21.2×22.1×11.6	1821.58	1.5	

Table 4.2.4.C. CSB’s Compressive Strength Tests Results using 10 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	23/7/2007	28	20.8×22.1×11.6	1781.6	3	3.0
2	25/6/07	23/7/2007	28	20.9×22.1×11.6	1791.74	3	
3	25/6/07	23/7/2007	28	21.2×22.1×11.6	1766.38	2.5	

Table 4.2.4.D. CSB’s Compressive Strength Tests Results using 10 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	20/8/2007	56	20.6×22.1×11.6	1704.21	3.5	3.2
2	25/6/07	20/8/2007	56	20.7×22.1×11.6	1790.20	3.0	
3	25/6/07	20/8/2007	56	20.5×22.1×11.6	1693.5	2.9	

Table 4.2.5.A. CSB’s Compressive Strength Tests Results using 12 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	2/7/2007	7	21.8×21.1×11.6	1986.59	1.7	1.7
2	25/6/07	2/7/2007	7	20.4×21.1×11.6	1988.63	1.8	
3	25/6/07	2/7/2007	7	20.7×21.1×11.6	1986.96	1.7	

Table 4.2.5.B. CSB’s Compressive Strength Tests Results using 12 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	9/7/2007	14	20.6×21.1×11.6	1923.82	1.7	1.8
2	25/6/07	9/7/2007	14	21.1×21.1×11.6	1936.32	1.8	
3	25/6/07	9/7/2007	14	21×21.1×11.6	1945.54	1.8	

Table 4.2.5.C. CSB’s Compressive Strength Tests Results using 12 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	23/7/2007	28	21.4×21.1×11.6	1890.08	3.4	3.4
2	25/6/07	23/7/2007	28	21.4×21.1×11.6	1870.99	2.5	
3	25/6/07	23/7/2007	28	20.7×21.1×11.6	1788.64	3.4	

Table 4.2.5.D. CSB's Compressive Strength Tests Results using 12 % RPC

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/6/07	20/8/2007	56	21.9×21.1×11.6	1790.96	4.2	4.0
2	25/6/07	20/8/2007	56	21.5×21.1×11.6	1805.28	3.9	
3	25/6/07	20/8/2007	56	20.5×21.1×11.6	1813.62	3.8	

Table 4.2.5.E. Mean compressive strength of CSB's using NPC

Mix code	Mean compressive strength [MPa]			
	7 days	14 days	28 days	56 days
NPC4				
NPC6	0.6	1.3	1.5	2.23
NPC8	1.1	1.8	2.1	3.2
NPC10	1.4	2.1	2.6	4.03
NPC12	1.5	2.5	3.5	5.03

Table 4.2.5.F. Mean compressive strength of CSB's using RPC

Mix code	Mean compressive strength [MPa]			
	7 days	14 days	28 days	56 days
RPC4	0.15	0.7	0.8	1.0
RPC6	0.4	1.0	1.6	1.85
RPC8	1.0	1.3	2.3	2.9
RPC10	1.3	1.7	3	3.2
RPC12	1.7	1.8	3.4	4

From these results general trends can be recognized. According to the tabulated results in Table 4.1.1.A to 4.2.5.F it would be reasonable to conclude that for a given constant compaction pressure, an increase in absolute compressive strength can be achieved by increasing the cement content. This increment in cement content results in deposition of cement gel between soil particles. The interlocking cement gel between the soil particles binds the soil particles together and creates high strength. The results also show that from the CSB's produced at the varying cement contents from 4 % in increments of 2 % up to 12 % at constant compressive pressure of 10 MPa, all the CSB's except those produced by 4 % cement had 28 day wet compressive strength values well above most of the recommended minimum values for use in structural work as per the literature. According to the literature, several different minimum values of 28 day wet compressive strength, all above 1.0 MPa are proposed; but the 56 day wet compressive strength of all the CSB's developed in this research were well above the minimum recommended values.

From the results shown above in Tables 4.2.5.E and 4.2.5.F, the rate of increase in strength can be approximated. The data reveals that the absolute increase in compressive strength appears to remain constant but then increases less at the lower cement contents but more at the higher cement contents. For instance, when the NPC content is doubled from 4 % to 8 % at constant compaction pressure, a compressive strength increase of 110 % is achieved; further doubling of the cement content from 6 % to 12 % would produce a projected increase in wet compressive strength of up to 135 %.

Table 4.2.5.G Rate of increase in CSB's compressive strength for NPC cement content increment

Mix code	**Cement content (%)**	**28th day compressive Strength(MPa)**	**Compressive strength % Increase**
NPC4	4	1	-
NPC6	6	1.5	50
NPC8	8	2.1	40
NPC10	10	2.6	24
NPC12	12	3.5	35

Table 4.2.5.H Rate of increase in CSB's compressive strength for RPC content increment

Mix code	**Cement content (%)**	**28th day compressive Strength(MPa)**	**Compressive strength % Increase**
RPC4	4	0.8	-
RPC6	6	1.6	100
RPC8	8	2.3	44
RPC10	10	3	30
RPC12	12	3.4	14

4.1.2 Comparison of Compressive Strength of CSB's Developed using NPC and RPC

In 2007, there were only three operating cement factories in Kenya namely Bamburi Cement company , Athi River Mining (ARM) company and East African Portland Cement Company (EAPCC's). Due to availability in the market, the researcher used only Bamburi NPC and ARM RPC as a stabiliser in this research.

For the production of NPC and RPC, factories use different types of raw materials as indicated in Tables 2.1 and 2.2, which in turn has an effect on the physical and chemical properties of the cement produced. These differences in the physical and chemical properties of NPC and RPC was thought to have a different stabilisation effect on CSB’s. In this section analysis of the test results is undertaken from the point of view of determining the comparative effect of each cement type on CSB’s. To check these effects different trial mixes were prepared as shown in Tables 3.1 and 3.2. It was observed that the 56th day compressive strength of CSBs stabilised using RPC had better compressive strength than those stabilised with NPC. The percentage differences are given in Table 4.2.5.I below.

Table 4.2.5.I Comparison of the 56th day compressive strength of CSB’s by using NPC and RPC as stabilisers

Cement type	Cement content by weight of soil and compressive strength of CSB in MPa				
	4%	6%	8%	10%	12%
NPC	1.25	2.23	3.2	4.03	5.03
RPC	1	1.85	2.7	3.2	4
*% difference	20	17	16	20	20

*Taking NPC as reference

4.1.3 Effects of Compaction Pressure on Compressive Strength of CSB’s

Although the stabiliser content could be responsible for binding, sealing, reinforcing and imparting flexibility to the CSB’s, compaction pressure could contribute towards increasing the densification and thereby reducing voids. The stabiliser increases the compressive strength and impact resistance of CSB, as well as reducing its tendency to swell and shrink; by sealing all voids and pores and providing a waterproofing film. The stabilizer may help to reduce cracking; conversely, by reinforcing the soil, the stabiliser may reduce excessive expansion and contracting. The effect of stabilisation is greatly increased when the soil is compacted. In the previously conducted experiments, all CSB’s were compacted prior to curing to a compaction pressure of 10 MPa, a value considered to be high enough to produce the best possible quality CSB’s. In subsequent experiments to follow, both the compaction pressure and the cement content was varied.

From the literature, improved levels of compaction have a significant effect on the compressive strength of the sample and on the effectiveness of the cement stabiliser added. The researcher proved this fact in the laboratory by using different compaction pressure and cement as indicated in Tables 4.3.1 to 4.6.4 below.

- **Effects of Compaction Pressure on the Compressive Strength of CSB’s by Using 6 % RPC**

Table 4.3.1 CSB's compressive strength test result by using compaction pressure of 4 MPa.

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	25/06/07	06/08/2007	28	25×21.1×11.6	1666.9	0.1	0.1
2	25/06/07	06/08/2007	28	24.5×21.1×11.6	1667.6	0.1	
3	25/06/07	06/08/2007	28	24×21.1×11.6	1668.7	0.2	

Table 4.3.2 Block compressive strength test result by using compaction pressure of 6 MPa.

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	06/08/2007	28	23.1×21.1×11.6	1715.6	0.9	0.9
2	9/7/2007	06/08/2007	28	23.7×21.1×11.6	1741.1	0.9	
3	9/7/2007	06/08/2007	28	23.2×21.1×11.6	1723.3	1.0	

Table 4.3.3 Block compressive strength test result by using compaction pressure of 8 MPa.

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	06/08/2007	28	23.6×21.1×11.6	1800.4	1.0	0.9
2	9/7/2007	06/08/2007	28	22.8×21.1×11.6	1809.9	1.2	
3	9/7/2007	06/08/2007	28	23.1×21.1×11.6	1802	1.2	

Table 4.3.4 Block compressive strength test result by using compaction pressure of 10 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	06/08/2007	28	21.8×21.1×11.6	1799.2	1.8	1.7
2	9/7/2007	06/08/2007	28	22.3×21.1×11.6	1795.5	1.5	
3	9/7/2007	06/08/2007	28	22×21.1×11.6	1791.4	1.7	

- **Effects of Compaction Pressure on the Compressive Strength of Soil Block by using 8 % RPC**

Table 4.4.1 Block compressive strength test result by using compaction pressure of 4 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	22.1×21.1×11.6	1737.8	1.3	1.3
2	9/7/2007	6/8/2007	28	22.1×21.1×11.6	1756.3	1.3	
3	9/7/2007	6/8/2007	28	22.5×21.1×11.6	1717.82	1	

Table 4.4.2 Block compressive strength test result by using compaction pressure of 6 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.8×21.1×11.6	1799.2	1.5	1.65
2	9/7/2007	6/8/2007	28	21.9×21.1×11.6	1809.6	1.8	
3	9/7/2007	6/8/2007	28	22.4×21.1×11.6	1829.6	1.6	

Table 4.4.3 Block compressive strength test result by using compaction pressure of 8 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.7×21.1×11.6	1845.1	2.0	2.1
2	9/7/2007	6/8/2007	28	21.5×21.1×11.6	1862.3	2.0	
3	9/7/2007	6/8/2007	28	21.4×21.1×11.6	1878.8	2.2	

Table 4.4.4 Block compressive strength test result by using compaction pressure of 10 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21×21.1×11.6	1906.6	2.5	2.6
2	9/7/2007	6/8/2007	28	20.9×21.1×11.6	1896.2	2.75	
3	9/7/2007	6/8/2007	28	20.4×21.1×11.6	1908.3	2.5	

- **Effects of Compaction Pressure On the Compressive Strength of Soil Block by using 10 % RPC**

Table 4.5.1 Block compressive strength test result by using compaction pressure of 4 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	23.1×21.1×11.6	1715.6	1.0	1.4
2	9/7/2007	6/8/2007	28	23.3×21.1×11.6	1736.0	1.4	
3	9/7/2007	6/8/2007	28	22.8×21.1×11.6	1765.0	1.5	

Table 4.5.2 Block compressive strength test result by using compaction pressure of 6 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.5×21.1×11.6	1805.3	1.8	2.2
2	9/7/2007	6/8/2007	28	21.4×21.1×11.6	1851.9	2.5	
3	9/7/2007	6/8/2007	28	21.7×21.1×11.6	1801.5	2.1	

Table 4.5.3 Block compressive strength test result by using compaction pressure of 8 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	20.3×21.1×11.6	1932.1	3.0	2.6
2	9/7/2007	6/8/2007	28	20.6×21.1×11.6	1884.2	2.5	
3	9/7/2007	6/8/2007	28	20.1×21.1×11.6	1912.1	2.4	

Table 4.5.4 Block compressive strength test result by using compaction pressure of 10 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	20.8×21.1×11.6	1885.7	2.5	2.75
2	9/7/2007	6/8/2007	28	20.8×21.1×11.6	1905.3	2.7	
3	9/7/2007	6/8/2007	28	20.8×21.1×11.6	1905.3	3.0	

- **Effects of Compaction Pressure on the Compressive Strength of CSB's by Using 12 % RPC**

Table 4.6.1 CSB compressive strength when compaction pressure is 4 MPa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	22.7×21.1×11.6	1727.8	1.5	1.8
2	9/7/2007	6/8/2007	28	22.5×21.1×11.6	1761.4	1.9	
3	9/7/2007	6/8/2007	28	22.7×21.1×11.6	1731.6	2.0	

Table 4.6.2 CSB compressive strength when compaction pressure is 6 MPa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.6×21.1×11.6	1834.8	2.5	2.4
2	9/7/2007	6/8/2007	28	21.8×21.1×11.6	1836.7	2.2	
3	9/7/2007	6/8/2007	28	21.5×21.1×11.6	1836.2	2.5	

Table 4.6.3 Block compressive strength test result by using compaction pressure of 8 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	20.8×21.1×11.6	1885.7	3.0	2.95
2	9/7/2007	6/8/2007	28	20.8×21.1×11.6	1964.2	2.8	
3	9/7/2007	6/8/2007	28	20.6×21.1×11.6	1896.1	3.0	

Table 4.6.4 Block compressive strength test result by using compaction pressure of 10 Mpa

Marking	Date		Age in days	Dimension L x W x H	Unit weight Kg/m^3	Compressive Strength Mpa	Average Strength MPa
	Casted	Tested					
1	9/7/2007	6/8/2007	28	21.1×21.1×11.6	1917.0	3.5	3.4
2	9/7/2007	6/8/2007	28	21.2×21.1×11.6	1936.3	3.2	
3	9/7/2007	6/8/2007	28	21.4×21.1×11.6	1927.2	3.5	

According to the tabulated results in Tables 4.3.1 to 4.6.4 above the compressive strength of CSBs was tested for various cement content samples ranging from 4 % to 12 % by differing the confining pressure from 4 % to 10 % with an interval of 2 Mpa for all cement content of samples. The results of this test proved that compaction pressure have an effect on the compressive strength of CSBs. The higher the compaction pressure the higher the compressive strength. When the compaction pressure was doubled from 4 MPa to 8 MPa at constant cement content of 8, 10 and 12, compressive strength was increased by 62 %, 86 % and 64 %, respectively.

4.1.4 Water Absorption

The experimental results of the water absorption test are tabulated in Table 4.7 below which shows the effect of cement content increase on the water absorption capacity of CSB's.

Table 4.7 Effect of cement increase on the water absorption of CSB's

Cement content	**Sample**	**WW**	**Wd**	**Absorption Wc**	**Absorption**
4	1	9492	8165	16.25	15.81
	2	9476	8214	15.36	
6	1	9629	8522	12.99	14.22

	2	9610	8324	15.45	
8	1	9991	8717	14.61	14.12
	2	9970	8774	13.63	
10	1	10285	9038	13.76	13.76
	2	10251	9021	13.63	
12	1	10189	9303	9.52	9.8
	2	10142	9213	10.08	

According to the tabulated results in Table 4.7, the mean water absorption values for the various samples tested range from 9.8 % for the 12 % cement content samples to 15.81 % for the 4 % cement content samples. From the literature the recommended maximum water absorption value for blocks is below15 %.

According to Table 4.7, an increase in cement content has the effect of reducing the water absorption value of the blocks produced at constant compaction pressure. A doubling of the cement content from 4 % to 8 % resulted into a reduction in mean water absorption of 10 %. A further doubling of cement content from 6 % to 12 % is projected to reduce the mean water absorption by 30 %. This shows that the increase in cement content results into a reduction in water absorption.

In practice, water can gain access to the block either in liquid phase in the case of rainwater infiltration or suction from a wet surface, or in the vapor phase in the case of condensation or adsorption, but leaves the block almost exclusively in the vapor phase through evaporation. Therefore the water content of the wall should be determined not only by its contact to water sources but also with its water vapor balance i.e., evaporation minus condensation and adsorption. Given that the block undergoes seasonal cycle with maximum water content in the rainy season and minimum water content in the dry season, such cycles constitute an added complexity in analyzing the moisture balance and therefore any remedial steps that could be taken.

4.2.1 Characteristics of Low Density Polyethylene

LDP has a melting point of 115 ^{0}C, a density of 0.925 g/cm^3, low tensile strength, high ductility, it is unreactive to strong oxidising agents, acids, most organic compounds except halogen compounds and can withstand temperatures of 80 – 95 ^{0}C for a short time. However, LDP exposure to light and oxygen results to loss of strength (Saechtling, 1987). LDP was melted at 115 ^{0}C. When some of the melt was put in an air tight container and allowed to cool for 24 hrs at room temperature, it solidified into a hard block.

4.2.2 LDP Melt Absorbed by CSB's

CSB's cured for 7 days and 28 days respectively were immersed into the LDP melt for 2, 4, 6, 8 and 10 min. Six blocks were used for each test. The blocks were left to cool down in air and observations were made. All the blocks which had cured for 7 days showed rough surfaces with swellings probably because of moisture trying to escape (Plate 1). CSB's cured for 28 days showed smooth surfaces (Plate 2). A cross section cut of the CSB's immersed into the LDP melt after curing for 28 days showed that the melt had penetrated a depth of 2 mm on each side of surface in all the blocks (Plate 3).

Coating CSB's by immersing them in the LDP melt is tedious, risky and difficult. To overcome this problem, there was need to mix the melt with solvent in order to produce a product that can be applied with ease like conventional coatings. Kerosene was used because it improves the coating brushability and flow by slowing down the over-all evaporation as opposed to the other solvents (Potter and Simmons, 1998).

4.2.3 Effect of Kerosene on LDP Melt

In order to convert the LDP melt into a liquid, varying amounts of kerosene at room temperature were added to the LDP melt at 115 ^{0}C. These melts were left to cool at room temperature for 24 hrs and observations were made. It was established that a ratio of 1 : 2 (v/v), LDP : Kerosene would stop solidification of LDP melt on cooling to room temperature. However, this ratio gave a liquid melt with suspended solids. To improve this melt, kerosene was added to LDP melt heated to selected temperatures. The same ratio of 1 : 2 (v/v), LDP : Kerosene was maintained. The best results were obtained when kerosene was added to LDP melt heated at 210 ^{0}C. The resulting melt was a liquid without any solids at room temperature.

4.2.4 Brushing Property of the LDP : Kerosene Melt

The brushing property of the LDP : Kerosene, 1 : 2 (v/v) melt was tested by applying the same on the surfaces of CSB's cured for 28 days. This LDP : Kerosene, 1 : 2 (v/v) melt took 6 hrs to dry and on drying formed a film which easily peeled off when gently rubbed.

In order to improve the LDP : Kerosene, 1 : 2 (v/v) melt properties, varying amounts of long drying oil alkyd resin (Synald 1070w long oil alkyd) were added. Drying oil alkyd resins contain alkene groups which react with oxygen from the air, resulting to cross linking, hardening and on drying forms a film (Standeven, 2003; Thomas, 2004). There are many resins which could have been used in this study for example, medium oil alkyd resin, short oil alkyd resin, urethane alkyd resin and polyurethane alkyd resin. However, long drying oil alkyd resin (Synald 1070w long oil alkyd) was selected because it is soluble in aliphatic solvents like kerosene, have good brushing properties, dries rapidly in air and gives reasonably durable, glossy films (Standeven, 2003;

Thomas, 2004). It was established that a ratio of LDP : Kerosene : Resin, 1 : 2 : 3 (v/v) melt, gave a dry film that did not crack or peel off when rubbed hard. However, the resulting dry film was transparent because it lacked pigments.

Plate 1. Appearance of CSB after curing for 7 days showing rough LDP melt coat

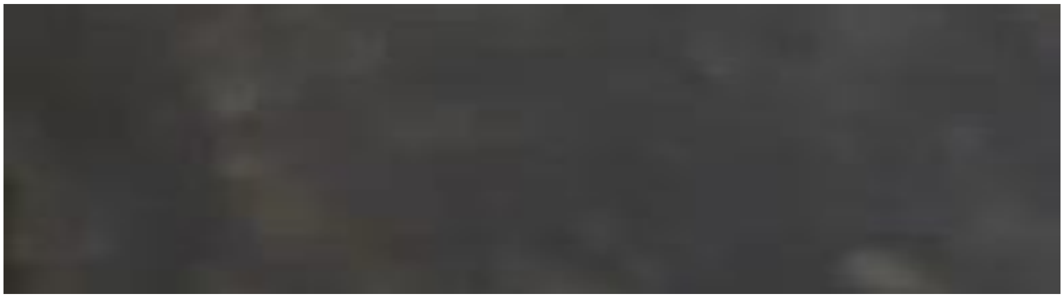


Plate 2. Appearance of CSB after curing for 28 days showing smooth LDP melt coat

Plate 3. Degree of absorption of LDP melt on CSB Cured for 28 days

In coatings, pigments are materials that change the color of reflected or transmitted light as the result of wavelength selective absorption. They must have high tinting strength relative to the materials they color and must be stable in solid form at ambient temperatures. Some of the pigments used in the paint industry include; titanium dioxide, lead oxide, zinc oxide, carbon black, chromium compounds, cadmium compounds and red iron oxide, which was used in this study. It was selected because it is opaque, have excellent covering power and do not react with organic solvents (Michael, 2007).

4.2.5 Effect of Red Iron Oxide on Improved LDP Melt Opacity

The opacity of a paint film is heavily dependent on the pigment contained within that film. In this research, red iron oxide was added to improve opacity of the improved LDP melt dry film. Experiments were done to establish the appropriate amount of red iron oxide to use. Fourty series (each with four replications) of the improved LDP melt with varying amount of red iron oxide were developed and their light scattering power on 25 µm dry film determined as shown in Table 4.8.

Table 4.8 Effect of Red Iron Oxide on the improved LDP melt

4	**3**	**2**	**1**	
1:0.04	1:0.03	1:0.02	1:0.01	**Improved LDP melt : Red Iron Oxide**
333.33	333.33	333.33	333.33	**Kerosene (ml)**
166.67	166.67	166.67	166.67	**Low Density Polyethylene Melt (ml)**
500.00	500.00	500.00	500.00	**Long Drying Oil Alkyd Resin (ml)**
40	30	20	10	**Red Iron Oxide (g)**
706.67	696.67	686.67	676.67	**Mass solids**
28.27	27.87	27.47	27.07	**Spreading Rate (M^2/L)**
0.0354	0.0359	0.0364	0.0369	**Usage Rate (L/M^2)**
35.37	35.88	36.40	36.94	**Wet film thickness (microns)**
70.67	69.67	68.67	67.67	**Volume solids (%)**
5.7	4.3	2.9	1.5	**Pigment volume concentration (%)**
5.00	5.00	5.00	5.00	**Low Density Polyethylene Cost (@ 0.03 Ksh/ml)**
30.00	30.00	30.00	30.00	**Kerosene Cost (@ 0.09 Ksh/ml)**
250.00	250.00	250.00	250.00	**Long Drying Oil Alkyd Resin Cost (@ 0.5 Ksh/ml)**
10	7.5	5	2.5	**Red Iron Oxide Cost (@ 0.25 Ksh/g)**
295.00	292.50	290.00	287.50	**Cost/Liter (Ksh)**
10.44	10.50	10.56	10.62	**Cost per hiding power (ksh/m^2)**
1.36	1.02	0.68	0.34	**Scattering coefficient (25 microns)**

13	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**
1:0.13	1:0.12	1:0.11	1:0.10	1:0.09	1:0.08	1:0.07	1:0.06	1:0.05
333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33
166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67
500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
130	120	110	100	90	80	70	60	50
796.67	786.67	776.67	766.67	756.67	746.67	736.67	726.67	716.67
31.87	31.47	31.07	30.67	30.27	29.87	29.47	29.07	28.67
0.0314	0.0318	0.0322	0.0326	0.0330	0.0335	0.0339	0.0344	0.0349
31.38	31.78	32.19	32.61	33.04	33.48	33.93	34.40	34.88
79.67	78.67	77.67	76.67	75.67	74.67	73.67	72.67	71.67
16.3	15.3	14.2	13	11.9	10.7	9.5	8.3	7
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
32.5	30	27.5	25	22.5	20	17.5	15	12.5
317.50	315.00	312.50	310.00	307.50	305.00	302.50	300.00	297.50
9.96	10.01	10.06	10.19	10.16	10.21	10.27	10.31	10.38
3.51	3.34	3.17	3	2.74	2.48	2.22	1.96	1.7

22	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**
1:0.22	1:0.21	1:0.20	1:0.19	1:0.18	1:0.17	1:0.16	1:0.15	1:0.14
333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33
166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67
500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
220	210	200	190	180	170	160	150	140
886.67	876.67	866.67	856.67	846.67	836.67	826.67	816.67	806.67
35.47	35.07	34.67	34.27	33.87	33.47	33.07	32.67	32.27
0.0282	0.0285	0.0288	0.0292	0.0295	0.0299	0.0302	0.0306	0.0310
28.19	28.51	28.84	29.18	29.52	29.88	30.24	30.61	30.99
88.67	87.67	86.67	85.67	84.67	83.67	82.67	81.67	80.67
24.8	24	23.1	22.2	21.3	20.3	19.4	18.4	17.4
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
55	52.5	50	47.5	45	42.5	40	37.5	35
340.00	337.50	335.00	332.50	330.00	327.50	325.00	322.50	320.00
9.59	9.63	9.66	9.70	9.74	9.79	9.83	9.87	9.92
4.3	4.3	4.3	4.21	4.12	4.03	3.94	3.85	3.68

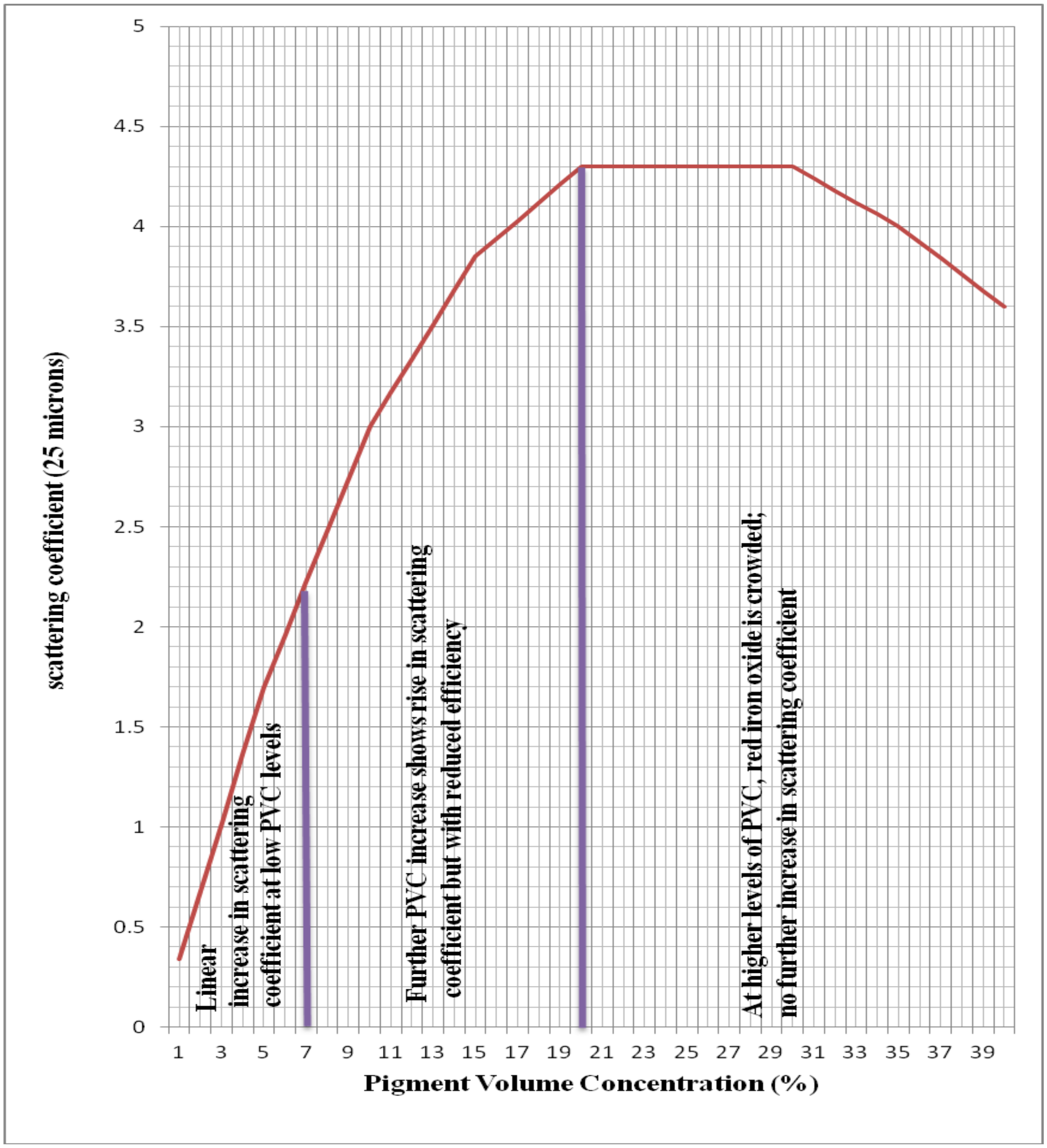
31	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**
1:0.31	1:0.30	1:0.29	1:0.28	1:0.27	1:0.26	1:0.25	1:0.24	1:0.23
333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33
166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67
500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
310	300	290	280	270	260	250	240	230
976.67	966.67	956.67	946.67	936.67	926.67	916.67	906.67	896.67
39.07	38.67	38.27	37.87	37.47	37.07	36.67	36.27	35.87
0.0256	0.0259	0.0261	0.0264	0.0267	0.0270	0.0273	0.0276	0.0279
25.60	25.86	26.13	26.41	26.69	26.98	27.27	27.57	27.88
97.67	96.67	95.67	94.67	93.67	92.67	91.67	90.67	89.67
31.7	31	30.3	29.6	28.8	28.1	27.3	26.5	25.7
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
77.5	75	72.5	70	67.5	65	62.5	60	57.5
362.50	360.00	357.50	355.00	352.50	350.00	347.50	345.00	342.50
9.28	9.31	9.30	9.38	9.41	9.44	9.48	9.51	9.62
4.24	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3

40	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**
1:0.40	1:0.39	1:0.38	1:0.37	1:0.36	1:0.35	1:0.34	1:0.33	1:0.32
333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33	333.33
166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67	166.67
500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
400	390	380	370	360	350	340	330	320
1066.67	1056.67	1046.67	1036.67	1026.67	1016.67	1006.67	996.67	986.67
42.67	42.27	41.87	41.47	41.07	40.67	40.27	39.87	39.47
0.0234	0.0237	0.0239	0.0241	0.0243	0.0246	0.0248	0.0251	0.0253
23.44	23.66	23.88	24.11	24.35	24.59	24.83	25.08	25.34
106.67	105.67	104.67	103.67	102.67	101.67	100.67	99.67	98.67
37.5	36.9	36.3	35.7	35.1	34.4	33.8	33.1	32.4
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
100	97.5	95	92.5	90	87.5	85	82.5	80
385.00	382.50	380.00	377.50	375.00	372.50	370.00	367.50	365.00
9.02	9.05	9.08	9.10	9.13	9.16	9.19	9.22	9.25
3.6	3.68	3.76	3.84	3.92	4	4.06	4.12	4.18

Through these experiments, the point beyond which increasing red iron oxide (pigment) decreased the efficiency of the individual particles as light scattering centers due to crowding effects was established to be 1 : 0.2 m/m (Improved LDP melt : red iron oxide) as shown in Fig. 1.

The scattering coefficient versus pigment volume concentration (PVC) plot in figure 1 shows two distinct regions. The first is a linear region up to 7 % PVC. In this region each further addition of pigment is yielding a proportional increase in scattering coefficient.

Fig. 1. Effect of Pigment Volume Concentration on Scattering Coefficient of the Waterproofing Agent Dry Film



This proportionality shows that each unit addition of pigment is scattering light with the same efficiency. However, in the second region above 7 % PVC, the plot becomes curved, demonstrating that at these higher PVCs there is a loss of scattering efficiency per unit addition of pigment. This loss of efficiency becomes more pronounced as the PVC is increased.

It can be seen that the scattering coefficient line begins to flatten out as PVC increases above 20 %. This is because the optical efficiency loss due to crowding becomes so large at high pigment loadings that it completely negates the increased number of scattering particles in the waterproofing agent film. Above 30 % PVC, the crowding effects reduce the efficiency to such an extent that increasing pigment content causes a reduction in scattering coefficient and the line begins to turn back down. Addition of extra pigment in these regions is inefficient.

4.3.1 Application Properties of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for application properties KEBS 03-909 (1991). According to this test, the coating should be easy to brush, should show satisfactory flowing, spreading, leveling and lapping properties. The coating film when dry should not show signs of sagging, running or streaking and should be free from brush marks. The waterproofing agent met all these requirements.

4.3.2 Condition in the Container of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for the condition in the container KEBS 03-910 (1991). According to this test, the coating should be free of gel, coarse particles, foreign matter, skin and be in such condition that at the time of delivery, manual stirring produces a homogenous product of uniform consistency. The waterproofing agent met all these requirements.

4.3.3 Drying Time of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for both surface and hard drying time KEBS 03-909 (1991). According to this test, the recommended surface drying and hard drying time should be a maximum of 4 hrs and 24 hrs respectively. The waterproofing agent did not meet either of these requirements because its surface and hard drying time was 6 hrs and 36 hrs respectively. This was caused by kerosene which had been used as a solvent since it does not dry as fast as other solvents used in conventional coatings (Potter and Simmons, 1998). Addition of dryers such as cobalt could have improved the drying time of the waterproofing agent, however, this was avoided because of their negative impacts on the environment when the waterproofing agent film age and start peeling off (Valør and Tinge, 2003).

4.3.4 Resistance to Washing of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for the resistance to washing KS 03-909 (1991). According to this test, after curing for 168 hrs, the dry waterproofing agent film should not wear out after subjecting it to the minimum 4,000 brushing strokes. The waterproofing agent met this requirement after subjecting it to 4,000 brushing strokes and its dry film did not wear out. This demonstrates that the waterproofing agent can be used for external application to protect CSB's from the wash off by the rains.

4.3.5 Opacity of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for opacity KEBS 03-910 (1991). According to this test, the maximum opacity recommended should be 90 µm. The waterproofing agent opacity was 40 µm and therefore, met the requirement. This implied that the waterproofing agent had very high covering power. It required very little waterproofing agent to be applied in order to form a thick dry film which could hide the underneath surface thus making it a very economical waterproofing agent to use.

4.3.6 Solid Content of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for solid content KEBS 03-910 (1991). According to this test, the minimum solid content recommended should be 50% (m/m). The waterproofing agent had a solid content of 42.5% (m/m) and therefore, did not meet the requirement. The level of solids in the waterproofing agent was below the recommended level because no solid fillers had been added. LDP melt was to replace the solid fillers in the waterproofing agent. However, the method used to detect the solids involved evaporating all the liquid in the waterproofing agent in order to get the solids during which the LDP melt was also evaporated and could not be accounted for.

4.3.7 Resistance to Accelerated Weathering of the Waterproofing Agent

The waterproofing agent was subjected to the standard test for accelerated weathering KEBS 03-811 (1997). According to this test, the waterproofing agent should not exhibit any flacking, cracking, chalking or colour fading after testing it in a xenotester apparatus for 42 hrs. Each hour was equivalent to 8 days. This implied that the waterproofing agent could withstand weathering for over 336 days when applied on the CSB's to protect them from wash off by the rains. The waterproofing agent met the conditions of the test. This demonstrates that it is a good waterproofing agent for external application and it will protect CSB's from harsh weather conditions.

4.3.8 Waterproofing Agent Ability to Protect CSB's from Water Destruction

Two sets of CSB's cured for 28 days were used. One set was uncoated and the other was coated with the waterproofing agent. Both sets of CSB's were immersed in a basin containing clean water at room temperature. After 24 hrs, the uncoated CSB's were weak and each had absorbed 1 kg of water while those coated did not show any change in strength or mass for 30 days of immersion in water.

4.4.1 Reformulation and Cost Considerations of the Waterproofing Agent

The following experiments were carried out to investigate the compromise between improving opacity and increasing formulation costs of the waterproofing agent (LDP : Kerosene : Resin : Red iron oxide 1 : 2 : 3: 0.2 m/m). Ten waterproofing agent series (each with four replications) were made using constant amounts (by weight) of red iron oxide per liter while varying the solvent and resin contents. The red iron oxide was set at 200 g/l.

These paints were applied to polyester film and their optical properties measured. The scattering coefficient for a 25μm dry film and the hiding power for a film resulting from 100μm wet paint were calculated using Kubelka-Munk equations (Michael, 2012). The results obtained are shown in Tables 4.9 and 4.10.

Table 4.9 Effect of reformulating the waterproofing agent

B	**A**	
(1 : 2 : 3.7) : 0.2	(1 : 2 : 3) : 0.2	**Improved LDP melt : Red Iron Oxide**
150	166.67	**Low Density Polyethylene Melt (ml)**
300	333.33	**Kerosene (ml)**
550	500.00	**Long Drying Oil Alkyd Resin (ml)**
200	200	**Red Iron Oxide (g)**
1200	1200.00	**Mass solids (grams)**
22.2	23.1	**Pigment volume concentration (%)**
90	86.67	**Volume solids (%)**
0.0278	0.0288	**Usage Rate (l/m^2)**
4.5	5.00	**Low Density Polyethylene Cost (@ 0.03 Ksh/ml)**
27	30.00	**Kerosene Cost (@ 0.09 Ksh/ml)**
275	250.00	**Long Drying Oil Alkyd Resin Cost (@ 0.5 Ksh/ml)**
50	50.00	**Red Iron Oxide Cost (@ 0.25 Ksh/g)**
356.5	335.00	**Cost/Liter (Ksh)**
9.9	9.66	**Cost per hiding power (ksh/m^2)**
36	34.67	**Spreading Rate (m^2/l)**
4.5	4.3	**Scattering coefficient (25 microns)**

I	H	G	F	E	D	C
(1 : 2 : 27) : 0.2	(1 : 2 : 17) : 0.2	(1: 2 : 12) : 0.2	(1 : 2 : 9) : 0.2	(1 : 2 : 7) : 0.2	(1 : 2 : 5.6) : 0.2	(1 : 2 : 4.5) : 0.2
33.34	50	66.67	83.34	100	116.67	133.34
66.66	100	133.33	166.66	200	233.33	266.66
900	850	800	750	700	650	600
200	200	200	200	200	200	200
1200	1200	1200	1200	1200	1200	1200
17.7	18.2	18.8	19.4	20	20.7	21.4
113.33	110	106.67	103.33	100	96.67	93.33
0.0221	0.0227	0.0234	0.0242	0.0250	0.0259	0.0268
1	1.5	2	2.5	3	3.5	4
6	9	12	15	18	21	24
450	425	400	375	350	325	300
50	50	50	50	50	50	50
507	485.5	464	442.5	421	399.5	378
11.19	11.03	10.87	10.71	10.53	10.33	10.13
45.33	44	42.67	41.33	40	38.67	37.33
5.7	5.7	5.5	5.3	5.1	4.9	4.7

J	(1 : 2 : 57) : 0.2	16.67	33.33	950	200	1200	17.1	116.67	0.0214	0.5	3	475	50	528.5	11.32	46.67	5.9

Table 4.10 Effect of Pigment Volume Concentration on Cost per Hiding Power of the Waterproofing Agent

	Pigment volume concentration (%)	**Cost per hiding power (Ksh/m^2)**
	23.1	9.66
	22.2	9.9
	21.4	10.13
	20.7	10.33
	20	10.53
	19.4	10.71
	18.8	10.87
	18.2	11.03
	17.7	11.19
	17.1	11.32
Mean		**10.57**
Standard Deviation		**0.528943**
Coefficient of Variation		**0.050042**

Waterproofing agent formulation J (LDP : Kerosene : Resin : Red iron oxide ; 1 : 2 : 57 : 0.2) emerged the best overall. It had the lowest usage rate of 0.0214 l/m^2, compared with formulation A which had the highest usage rate of 0.0288 l/m^2. It would require 214 ml of formulation J to achieve one meter squared hiding power compared to 28.8 ml from formulation A.

It had the highest spreading rate of 46.67 m^2/l compared to formulation A which had the smallest spreading rate of 34.67 m^2/l. One liter of formulation A can therefore be used to achieve hiding power over an area which is 1.4 times bigger than formulation A.

Formulation J had a dry film with the lowest pigment volume concentration (PVC) of 17.1 % compared to formulation A whose dry film had PVC of 23.1 %. When the same amount of formulation J and A were applied on an equal surface area, pigments in formulation J were more sparsely distributed since they were fewer compared to those in formulation A which were overcrowded.

Each pigment in formulation A was able to scatter the light reaching it compared to pigments in formulation A where light could only reach those pigments which had not been hidden by others due to overcrowding resulting into less light being scattered. This made formulation J to have the highest hiding power with scattering coefficient of 5.9 µm compared to formulation A with scattering coefficient of 4.3 µm giving it the lowest hiding power.

Cost per hiding power for formulation J was highest at 11.32 Ksh/m^2 compared to formulation A whose cost per hiding power was the lowest at 9.66 Ksh/m^2. However, cost per hiding power between all formulations from A to J was not significantly big. With a mean of 10.57 and a standard deviation of 0.5, coefficient of variation between the formulations was 0.05. Since coefficient of variation was less than 1, it was not significant (Vic, 2012). However, if one or more of the raw material costs changes the coefficient of variation will either increase or decrease. These results made formulation J to qualify as the best waterproofing agent.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

- Through this research, low density polyethylene (LDP) waste was developed into waterproofing agent, which can be used for protecting cement soil blocks (CSB's) from water destruction. LDP melt was found to form a solid block on cooling and could only be applied on CSB's when hot through immersion. Most coatings are applied in liquid form at room temperature. Kerosene was added to the hot (115 ^{0}C) LDP melt, which on cooling did not solidify but formed a liquid melt with solid suspensions. On adding kerosene to hot (210 ^{0}C) LDP melt, it formed a liquid melt without suspensions after cooling at room temperature for 24 hrs. However, on application of LDP : kerosene melt on CSB's, it was observed that the melt had little covering power and also formed cracked film surfaces. To overcome this drawback, long drying oil alkyd resin was added to the melt to stop cracking of the film, while red iron oxide was added to improve its hiding power. The resulting improved melt was the expected waterproofing agent.

- This waterproofing agent was tested using standards for interior and exterior semi-gloss solvent borne paints according to Kenya Bureau of Standards specifications. The waterproofing agent satisfied all standards on; condition in the container, application properties, finish, opacity, resistance to washing and resistance to accelerated weathering. The waterproofing agent did not meet standards for solid content and drying time. However, failure to meet some of these standards did not affect its intended use. When CSB's cured for 28 days were coated with the waterproofing agent and immersed in clean water at room temperature for thirty days, their mass did not change. The waterproofing agent therefore, proved to be a good CSB's waterproofing agent.

- This research has provided a method for converting low density polyethylene (LDP) into CSB's waterproofing agent. In doing this, LDP waste materials will be removed from the waste stream. LDP waste clog sewer lines and storm water drains. When eaten by animals, fish or birds, their digestive systems get blocked resulting to death. Areas where they are dumped become aesthetically unsightly. Utilizing LDP will help to mitigate these environmental problems associated with them. Application of the waterproofing agent on CSB's will stop them from absorbing water therefore increasing their durability. This will increase the uptake of CSB technology which is environmentally friendly.

5.2 Recommendation

- It is recommended that further research should be conducted to establish other possible useful applications of the waterproofing agent like on timber, metal among others.
- Further research should be conducted to establish the extent to which LDP waste materials can be developed into other useful products like tar, shoe polish, fabric materials among others.

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