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Regassa, Yirdaw

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BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY

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WASTE PAINT VALORIZATION FOR CONCRETE TILES PRODUCTION

BY

YIRDAW REGASSA

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By

YirdawRegassa

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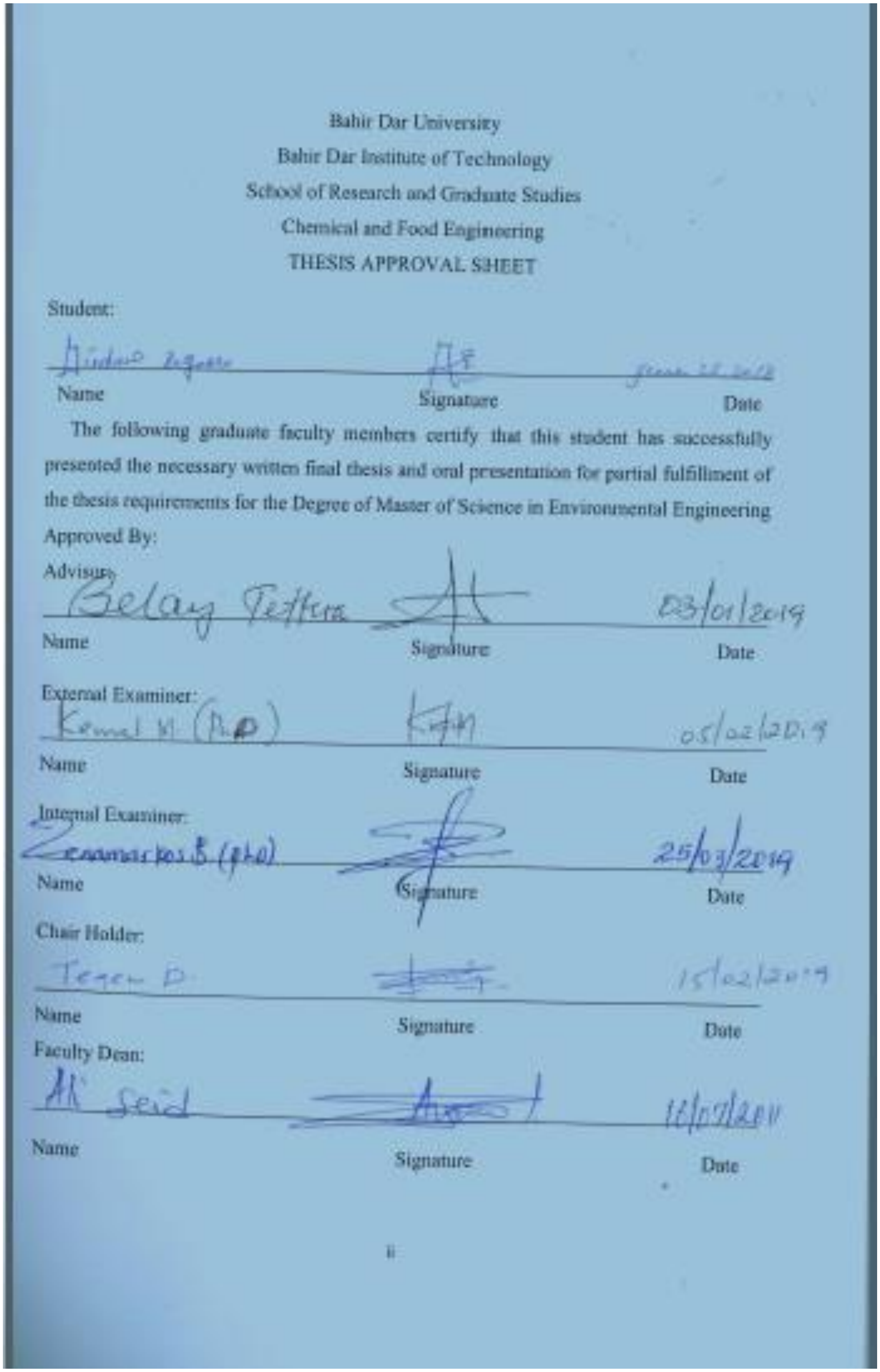

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Bahir Dar Institute of Technology
School of Research and Graduate Studies
Chemical and Food Engineering
THESIS APPROVAL SHEET

Student:

[illegible] [illegible]

Name Signature Date

The following graduate faculty members certify that this student has successfully presented the necessary written final thesis and oral presentation for partial fulfillment of the thesis requirements for the Degree of Master of Science in Environmental Engineering

Approved By:

Advisor:

Belay Teffera 03/01/2019

Name Signature Date

External Examiner:

Kemal M (PhD) 05/02/2019

Name Signature Date

Internal Examiner:

Zeramarkos B (phd) 25/03/2019

Name Signature Date

Chair Holder:

Tegen D. 15/02/2019

Name Signature Date

Faculty Dean:

Ali Seid 18/07/2011

Name Signature Date

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ABSTRACT

Waste paint (WP) has the potential to become a serious environmental burden in the future with very limited safe disposal options. One potential avenue for the disposal and consolidation of this waste is by stabilizing it in concrete pavement tiles and if deemed viable, such application can be practiced in a large scale in the country's concrete walkway making industry. In this study, experiments were made to assess the effects of WP on the mechanical properties of tiles if it is incorporated in different proportions (10%, 20%, 30%, 40% and 50%) by weight as partial replacement for mixing water. The objective was to explore the viability of waste paint as a concrete walk tile constituent and determine the effectiveness of such tile as a safe option for waste paint stabilization.

Test results indicate that the compressive strength of tiles incorporating 20-50% WP decreases which iseither due to the retarding effects of paints or the increase ofvoid spaces in tiles as a foaming effect of paints. On the other hand, tiles incorporating 10% of waste paint develops a better strength than that of the reference mixture at the age of 28 days. However, a general increase in the compressive strength of all tiles was observed with curing time which is due to the polymer film formation of the hardened concrete.

The water absorption of tiles in general decreaseswith the increase of waste paint proportion when compared with the reference mixture which is also due to the formation of polymer film which makes the concrete water tight. The test further indicates that tiles produced with the use of hydraulic pressing machine shows an overall improvement both in terms of compressive strength and water absorption than tiles produced under laboratory conditions. This is due to the pressure applied from the pressing machine which make tiles highly compacted.

Also by valorizing WP in concrete, there is a possibility to save water & reduce CO_2 and energy by reduction in the amount of virgin polymers required for PMC. Therefore, tiles incorporating a specified proportion of WP have been found to meet ASTM C902 requirements for building construction material. Results from this study indicate that waste paint can be sustainably stabilized in concrete walk tiles and large-scale application of this technique can be envisaged for Ethiopia where both the paint and tile industries continue to be important economic pillars of the country.

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LIST OF ABBREVIATIONS

A&D	Architectural and Decorative
ATTM	American Society for Testing Materials
BS	British Standard
CaO	Calcium Oxide
$Ca (OH)_2$	Calcium Hydroxide
CO2	Carbon Dioxide
EPA	Environmental Protection Authority
Fe_2O_3	Iron Oxide
KG	Kilo Gram
Kg/Cm^3	Kilogram per cubic centimeter
LMC	Latex Modified Concrete
LOI	Loss on Ignition
M^3	Meter cube
MEK	Methyl Ethyl Ketone
MFFT	Minimum Film Forming Temperature
MgO	Magnesium Oxide
MIBK	Methyl Isobutyl Ketone
MPa	Mega Pascal
O_2	Oxygen
OPC	Ordinary Portland cement
PC	Polymer Concrete

PIC	Polymer Impregnated Concrete
PMC	Polymer Modified Concrete
PSI	Product Steward Institute
PVA	Polyvinyl Acetate
SA	Styrene Acryl ate
SB	Styrene Butadiene
SBR	Styrene Butadiene Rubber
SCC	Self-Compacting Concrete
SiO_2	Silicon Dioxide
SL	Sika Latex
SO_3	Sulphur Trioxide
U.S.	United States
VAE	Vinyl Acetate Ethylene
VOC	Volatile Organic Compound
W/C	Water to Cement Ratio

LIST OF SYMBOLS

^0C	Degree Centigrade
%	Percent
μm	Micrometer

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CHAPTER ONE

1. INTRODUCTION

1.1. Background

Paint is a liquid chemical product which is applied in layers to protect, decorate or finish a solid surface and which hardens to form a solid coating. The change to a solid state of paint may result through solvent evaporation, by chemical reaction or by a combination of these processes. WithEthiopia experiencing significant construction and infrastructure growth and as an economic boom is currently driving the country towards industrialization, the paints & coatings industry is quickly becoming a strategic growth market. Being attracted by this growing market, many national and international companies have joined the paints production and distribution processes in the country.

Despite this fact, this industry is becoming one of the concerns nationwide due to adverse environmental impacts related to the poor management practices of liquid waste paints.Waste paint is a paint product that is getting contaminated with foreign materials while paint containers are opened or burst on transportation trucks or in retail shops due to unbalanced overlying weight. The contaminated paints thus do not get used for its intended purposes. As a result, it will be collected & returned back to store for reprocessing and repacking otherwise for disposal at the expenses of the company.

However, paint reprocessing is not practiced in most paint manufacturing industries due to the escalating cost of reprocessing operations. Even after reprocessing, people’s perception to purchase and use reprocessed paint is low due to its inferior quality as compared to original brand paints. The easiest way to get rid-off such waste is therefore to dispose it.

When such wastes are dumped in to the river valleys, it may cause turbidity of the drainage system which will then deleterious to human beings, animals, fish and aquatic life. When it is buried underground, it may results in the contamination of soil and ground water resources due to leaching of heavy metals. When leached and disseminated, these heavy metals are harmful to the sub-surface environment because of their non-biodegradable nature, long biological half-lives and their potential to accumulate in biological systems (Manahan, 2005; Wilson and Pyatt, 2007). Metal-containing waste paint if entered in agricultural land is also risky, because these metals may be taken up by the crop roots and incorporated into the plant tissue. Ultimately, these toxic metals can get entrance into the human body and lead to bio-accumulation and bio-magnification.

To reduce these risks, management solutions need to be in place to collect, valorize or dispose waste paint in sustainable ways. With this regard, two options have been investigated to manage waste paint in an environmentally safe manner. The first option is to reuse paint up on reprocessing which is found to be not feasible as discussed before.The second option is valorizing of waste paint in concrete. WP can be valorizedfor the production of concrete tiles in two ways; as a partial replacement for mixing water or as a partial replacement for virgin polymer latex currently used in certain types of concrete.

The application of these polymeric admixtures in concrete was not new. It dates back to 1920’s (Ismail et al, 2011). The concept of using waste paint in concrete was then come in to being from the similarities and functions of the basic constituents in paints (polymers & surfactants) and polymeric admixtures. Mohammed et al. (2008) studied the use of WP in concrete as a partial replacement for mixing water. In conducting the experiment, different proportions of WP were added to concrete and compared withvirgin latex concrete. Results indicated that by adding WP, the properties of ordinary concrete wereimproved and comparable to regular Latex Modified Concrete (LMC). In this case, WP was able to form a polymer film in concrete and its pigments and extenders fill additional porosity, which improves the long-term durability of concrete.

Nehdi and Sumner (2003) had also reported some observations about concrete produced for footpath (with 50% mixing water replaced with WP). The ease of construction, enhanced workability, distinctly lighter and more reflective color, not exhibiting coarse pop-outs, and no signs of surface scaling were amongst the advantages of this experimental sidewalk tiles compared to a reference sidewalk tiles.Valorizing waste paint as a replacement for polymer in Polymer Modified Concrete (PMC) can also be potentially make this product more cost effective and preserves and improves the positive properties of PMC (Quiroz, 2011).

Regarding its volume, an estimated amount of 178 million liters of paints are produced in the country annually (Table 1.1) below. From this, about3.56 million liters will be generated as waste per annum if all paint industries have become operational. This estimation was made based on the waste generation rates calculated (Table 2.1), which is 2% of the projected total production of paints. Out of this waste, about 70% (2.5 million) liters are considered to be water based paints which is the focus of this study. On the other hand, the use of concrete walk tiles hasbeen widely experiencedin the major cities of the country andwill continue to be so in the future.

Therefore, exploring the concrete walk tiles manufacturing industry as a potential avenue for valorization of the huge amount of waste paint in Ethiopia can be a viable option for commercial application. The objective of this research work is therefore to investigate the viability of water based waste paints valorization in concrete walk tiles, which is a dominant walk way construction material in Ethiopia.

Hence, concrete walk tile specimens will be produced with different proportions of waste paint in both laboratory controlled conditions and field conditions (i.e. in a hydraulic pressing machine) and its suitability as an engineering material will be assessed based on its compressive strength and water absorption characteristics.

Major environmental impacts and considerations associated with valorization of WP in concrete will be also reviewed to demonstrate the effectiveness of the valorization technique against the release of heavy metals in the environment.

1.2. Production of Paints in Ethiopia

The history of Ethiopian paints industry has come a long way from when paints were expensive and considered as a luxury item. It was in the 1967 that the first paints industry was established in Ethiopia with the brand name of Mega Paints, which later changed to Nifas Silk Paints. Since then individual consumers and companies have gradually reaching at high awareness levels about the benefits of paints which in turn has boosted the demand for this commodity. The booming of infrastructure development activities in the country such as building of industrial plants, real estate properties, condominium houses, public institutions, roads, bridges and the manufacturing sectors as a whole over the last couple of years have also provided decent opportunities for the growth of paints market in the country. As a result, the paints industry has supposed to contribute a lot in the economic growth of the country for the last few years.

Currently, there are about 22 paints manufacturing industries in Ethiopia operating at varying capacities and scales of operation (Chemical and Construction Input Industry Development Institute, 2008). The aggregate production capacities of these industries are estimated at 178 million liters based on 300 net working days per annum (Table 1.1) below. However, due to the competitive nature of the industry and the fact that some of these companies lack good distribution network & access to financing, only very few companies dominate the paints market.

Accordingly, products from companies like Nifas Silk, Zemilli, Kadisco, DIL, Rodas, Bright and Abay paints are the highly known brands and dominate the majority of the paints market in Ethiopia. Almost 50% of the paints production in the country is coming from these known brands with their attainable and estimated capacities indicated hereunder in Table 1.1.

Table 1.1.**Annual Paints Production in Ethiopia (‘000)**

S/No	Name of companies	Attainable annual Capacity (Lit) (2016/17)	Estimated annual production capacity (Lit)
1	Nifas Silk Paints	21,629	50,000
2	Zemilli Paints	19,256	50,000
3	Kadisco Paints	16,045	50,000
4	DIL Paints	13,088	40,000
5	Rodas Paints	9,896	40,000
6	Bright Paints	9,246	30,000
Total		**89,160**	**260,000**
Others (Estimated)		89,160	260,000
Grand Total		**178,320**	**520,000**

Source: Field Survey, 2017/18

Regarding their regional distribution, almost 85% of the paint industries are concentrated in and around the city of Addis Ababa. It is often the case that the production is being processed in Addis Ababa, but is then transported to all over the country. This is a consequence of the fact that the demand is mainly high in the capital where different construction activities are taking place and hence suppliers are concentrated in Addis Ababa as well. In this case, the city of Addis Ababa can be described as the center and main market for paint products in Ethiopia.

1.3. Problem Statement

Considerable efforts has been made so far by the paint industries globally in dramatically reducing environmental impacts through eliminating mercury, and reducing lead and the volatile organic compounds (VOCs) in paints. Significant improvements have also made in the performance of water based paints over solvent-based paints. This has been witnessed by the increased in production and sales volume of water based paints over solvent-based from 30-35% in the 1970's to over 80% currently (Paint Product Stewardship, 2004). Similarly in Ethiopia there is a clear trend in the manufacturing of paints away from solvent-based paints and towards water based-paints.

Nevertheless, there are still significant volumes of wastes are generated by the paint industries and released to the open environment unsafely. Among these, waste paint is considered as one of the hazardous wastes disposed in the environment with little care. In our case, the consequences was worsen due to the fact that most of these industries were established along the river valleys from where they released their waste paints to storm drain during rainy season. Others also dump this waste in to open pit along with paint sludge or buried underground in their production premises. This waste, which is highly rich in suspended solids, stable emulsions, dyes or pigments, acids, alkalis, heavy metals and organic solvents may cause severe problem though the impacts are far lower in the case of water based paints which contains from 50% - 90% water.

In light of the above, one can recognize that the contamination of water resources by such hazardous substances may harm living organisms and the whole ecosystem. There is also the potential to harm human health through bioaccumulation through the food chain, contamination of public water supply, and recreational use of contaminated water resources. Because these kinds of contamination threaten human health and living environments, measures to manage them are extremely important. So waste paint can be stabilized in concrete products either as a substitute for virgin latex or mixing water thereby reduce the environmental burden of its disposal.

1.4. Justification

Currently, many paint manufacturers are facing the challenge of managing waste paints which keep on growing trend due to the increased in production and distribution of paints to different regions or localities for sale. In course of these activities, paint products are getting contaminated with foreign materials due to opening or bursting of paint containers. These contaminated paints are thus regarded as waste and can’t be used for its intended application. At the end of the day, these defected paints are collected and subjected for reprocessing or repacking. However, there are certain circumstances in that paint reprocessing was found to be not a feasible option for waste paint management which will be discussed later in section 2.6 of the literature review.

On the other hand, waste paint is considered as a valuable resource which exhibits many properties similar to polymeric admixtures currently used in the production of certain concrete products. The use of these polymeric admixtures in concrete increases the matrix bond between cement and aggregate and to enhance the workability and flow of cementitious materials, but they are often too expensive for many applications. In this study, valorization of waste paint in concrete would be investigated to determine the potential use of WP as a viable admixture in non-structural concrete applications such as in sidewalk tiles at relatively low cost.

1.5. Research Hypotheses

There are effective means of waste paints management options to reduce its significant consequences.

1.6. Objectives of the study

1.6.1. General Objective

The general objective of this study is to evaluate the valorization potential of waste paints for concrete walk tiles production.

1.6.2. Specific Objectives

The specific objectives of the study are:

-To assess the effect of using waste paint as concrete admixture on the strength and other physical properties of concrete walk tiles.

-To assess the environmental and economic viability of waste paint valorization in concrete walk ties production.

-To propose an optimum waste paint-water proportion that can be used for concrete walk tiles manufacturing.

- To characterize waste paints to be used for concrete tiles production.

1.7. Significance of the study

There is very little literature relating directly to waste paint management practices in developing countries like Ethiopia. However, some literatures and publications in developed countries tend to suggest the possibility of valorizing waste paint in certain concrete products to improve some of its properties thereby maintaining environmental quality.

The output of this study will therefore be significant in:

A. Promoting waste paint as a valuable resource in concrete production.
B. Providing useful information to paint manufacturers for integrating their industry with concrete production.
C. Providing information to government & other stakeholders for the need of policy formulation on waste paint collection and management systems.
D. Initiating researchers and government organizations to conduct further research and comprehensive studies in the area.
E. Promoting waste paint collection and reprocessing as one scheme of job creation opportunities.

1.8. Scope and limitations

1.8.1. Scope

The scope of this study is limited only to two water based paint brads, DIL Mica and DIL Super Paints to produce concrete specimens of standard sizes of 200x100x60mm. This is mainly due to considerable material requirements and stringent safety precautions needed for solvent based paints to use in the experiment. Moreover, water based paints accounts for the largest volume of waste paint generation in paints manufacturing industry.

1.8.2. Limitations

All information for the experiment was organized based on the necessary data obtained from interviews and laboratory test results. To obtain sufficient data through interviews, it needs strong willingness and cooperation from industry owners, top managements and experts. However, there were certain instances that adequate information was not gathered due to unwillingness of same. This situation was considered as one of the challenges during the research and may to some extent affect the comparativeness of the study.

1.9. Thesis Structure

This thesis has consisted of six chapters arranged carefully in the order of step to make it clear and understandable. This section presents a brief description of these chapters.

General background about waste paint is presented in this **Chapter (1).** In this chapter, problem statement, justification, research hypothesis, objectives of the study, significance of the study and scope of the study are given.

Literature review about waste paint in general is given in **chapter (2)**. This literature review includes paints and its varieties, ingredients, manufacturing processes, waste quantification and environmental concerns of paints. This chapter illustrates also the existing options to deal with waste paint worldwide and how to convert the waste into safe and sustainable material which involves paint reuse & paint valorization in other products.

With this regard, relevant previous research works on the use of waste paint in concrete was discussed in brief. Moreover, discussions were also made in this chapter to signify the similarities and functions of the active constituents in paints and polymeric admixtures and the general principles of polymer modification in concrete.

A description of the methodology followed in conducting the experimental programs were given in **Chapter (3)**.This involves methodological approach to conduct the study in general and characterization of raw materials in particular. This chapter also outlines methods used in design of mix proportions, mixing process, specimen production, curing conditions, and standard tests on concrete products.

Chapter(4) deals with discussion of results which forms the core part of the study and consists ofraw materialscharacterization(such as cement, aggregates, waste paint/Sika latex, pigment, water, etc.) and concrete specimens (compressive strength and water absorption).Analysis of data and discussions were expressed in texts, figures, tables and the like.

Chapter (5) deals with economical &environmental aspects of waste paint inconcrete includingeconomic considerations, positive and negative aspects of WP in concrete, etc.

Conclusions derived from experimental results are presented in **Chapter (6)**.Finally recommendations for further studies on this subject will be provided in this chapter.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Paints

Paint is a suspension of finely separated pigment particles in a liquid that when spread over a surface in a thin layer will form a solid, cohesive, and adherent film. Paint products can be categorized either according to their use or type of carrier used in production (TGM for Integrated Paints Industry, 2010). Based on their use, paint products can be grouped into architectural, product finishes, and special purpose coatings (CEH, 2002).

a)Architectural coatings (45% of global coatings) are interior and exterior coatings used to decorate and protect new construction as well as to maintain existing structures, including residential homes and apartments, public buildings, offices, institutions, and factories;

b) Product finishes (40% of global coatings) are coatings that are applied to manufactured goods as part of the production process, for the purpose of protection or decoration;

c)Special purpose coatings (15% of global coatings) are used for miscellaneous applications such as traffic paints, automotive refinishing, high-performance coatings for industrial plants and equipment and protection of marine structures and vessels.

d) Other Paint Products include varnishes, stains, thinners, cleaning solvents, and strippers. Varnishes, for example, differ from conventional coatings in that they are solutions of film formers in organic solvents and do not contain pigments. Their function is merely to protect the surface. Stains are a hybrid of paints and varnishes since they contain some coloring material but are generally transparent.

Based on carriers used in formulation, paint products can be classified as solvent based and water based paints. Solvent-based paints usually use petrochemical products, such as mineral spirits, toluene or xylene as a solvent. These solvent-based paints include enamels, varnishes, and furniture lacquers and soluble in hydrocarbon and oxygenated solvents but not in water.

On the other hand, Water-based paints are formulated with water, thinned with water, and cleaned up with water which includes latex and water colors.The vehicle, solvent or water, evaporates after the paint has been applied to the surface of the object being painted. The paint cures as the evaporation takes place.The majority of architectural paints are water based, whereas, product and special purpose paints are solvent based.

2.2. Paint Ingredients

In order to have a general knowledge on paints, it is necessary to know the characteristics of materials from which this chemical is produced. Though more than 80 line items are required to produce these chemicals, the major ones are grouped in to binders (resins, drying oils), solvents, pigments, extenders, petroleum thinners, additives/chemicals, etc.

Binders: Binders form a continuous phase, hold the pigment together in dry film and cause it to adhere to the surface to be coated. The majority of binders in paint films are composed of resins and drying oils, which are largely responsible for the protective and general mechanical properties of the film. Resins provide characteristics such as durability and flexibility. Alkydes, acrylics and vinyls are the three commonly used resins (Johnson et al., 2009).

Solvents: Solvents are used to keep paints in liquid form so that they can be easily applied and evaporate completely. It is used to transfer the pigment mixture to a surface in a thin, uniform film and plays no role in film formation. Paint solvents are either organic liquids or water. Organic solvents are primarily hydrocarbons and oxygenated solvents.

- Hydrocarbons are the most common solvents used in paint and are divided into two categories; aliphatic and aromatic. The most commonly used aliphatic solvent is mineral spirits. Aromatic solvents provide stronger solvency, but with a greater odor. The most common are toluene, xylene, and naphtha.
- Oxygenated solvents include ketones, esters, glycol esters, and alcohols and are widely used with synthetic binders. Ketones are characterized by their strong odor, range of water solubility and evaporation rate. Esters provide solvency nearly equal to ketones but with more pleasing odors. Glycol ethers, used in low levels in water-borne paints, are milder in odor and display water miscibility, strong solvency, and slow evaporation.

Pigments: are finely ground, insoluble, dispersed particles that provide a coating formulation with color and opacity. They also can function as fillers, reinforcements and property modifiers. Pigments can be either natural or synthetic and inorganic or organic. The most widely used pigment in the paints manufacturing industry is titanium dioxide, which is white in color and inert. The rest of colored pigments are usually rich in polluting metals such as lead, cadmium, antimony, copper, zinc, chromium, cobalt, arsenic, antimony and others, though some of them are banned in some developed and developing countries (Hassan, 1984).

Extenders or Fillers: is special type of pigment that serves to thicken the film, support its structure, increase the volume of the paint and reduce costs of manufacturing. They comprise of cheap and inert materials like diatomaceous earth, talc, lime, clay among others.

Additives: are chemicals that facilitate the production, application, and performance properties of paints. Plasticizers, which are added to increase flexibility, account for almost one-quarter of the additives. Surface-active agents function as emulsifiers, pigment suspension aids and wetting agents. Other additives include thickeners (such as cellulose ethers), dryers, anti-skinning agents, anti-flooding agents, corrosion inhibitors, biocides, surfactants, dispersing agents, antifoams, and catalysts, etc.

2.3. Manufacturing Processes

In most cases, paint manufacturers purchase raw materials and then formulate or blend, rather than react to produce a finished product (Paint Product Stewardship, 2004). The production of paintsin a typical paint industryinvolvesthe weighing of dry pigments andfeeding through hoppers or chutes into mills wheremixing of material takes place with appropriate resin vehicle. The homogenized pigments is then transferred to a high speed mixer where thinners, drying agents, etc., may be added to adjust consistency, viscosity, color and drying time. When mixing is completed and the required consistency is achieved, the paint is filtered to remove any non-dispersed pigment and transferred to a loading hopper. From the hopper, the paint is poured into cans, labeled, packed, and moved to storage.

2.4. Waste Quantification

Waste quantification was found to be a difficult task in this study as actual figures about the quantity of waste paints is inaccessible and not calculated or monitored by the government or any other party. In developed countries, such activities are accomplished by an independent institution which have equipped with the necessary resources. For example, Product Stewardship Institute (PSI) is an independent organization in the US who is responsible for undertaking studies and inventories on all waste types generated in the country.

According to the report of this institution, the annual national generation of waste paints in the US is ranging from 2.5% to 5% of sales in the year 2000 (Paint Product Stewardship, 2004).Although reliable data is difficult to find, the amount of waste paints generated in Ethiopia was estimated through reviewing all available data on returned waste paintsof selected paint industries in the country. In this regard, a five years data (2009/10-2013/14) of two paint companies were summarized below in Table 2.1for analysis.

Table 2.1.Annual Returned Paints for Reprocessing

S. No	Years	Company 1			Company 2		
		Annual sales (Lit)	Returned paints (Lit)	%	Annual sales (Lit)	Returned Paints (Lit)	%
1	2009/10	5,289,627	100,505	1.90	4,156,103	83,122	2.00
2	2010/11	5,485,371	104,220	1.89	6,175,012	129,675	2.10
3	2011/12	5,931,821	124,568	2.10	8,364,450	158,924	1.90
4	2012/13	6,666,709	133,335	2.00	11,752,128	246,795	2.10
5	2013/14	8,021,293	176,468	2.20	19,343,215	425,550	2.20

Total	**31,394,821**	**639,096**	**2.03**	**49,790,908**	**10,440,066**	**2.10**

Source: Company Reports, 2009/10-2013/14

From the table above, one can see that the average amount of waste paints generated from a typical paint industry is estimated at 2% of the total sales with the assumption that all the produced paints are subjected to sold. This figure indicates a lower percentage as compared to the US generation rate which might be due to improvements in packing material quality and implementation of better transportation systems.

With conservative assumption that other paint industries also generate waste at similar rate to the companies mentioned above, the total amount of waste paintgenerated throughout the paints production and distribution processes is estimated at 3.56million liters. This is based on the current estimated production rate of 178million liters of paints per annum. 70% of this waste, i.e., 2.5million liters is water based paints (Table 1.1), which is the concern of this study to valorize the resourcesfor concrete sidewalk tiles production.

Furthermore, returns of waste paints are likely to dramatically increase in the future when the existing paint industries and other new entrants would have attained their full capacity operation.

2.5. Environmental Concerns

Paint industry is considered as one of the most environmentally unfriendly industries as its manufacturing processes add hazardous wastes/chemicals to the environment. Some of the major wastes related to this industry includes empty raw material packages, dust from air pollution control equipment, equipment cleaning wastes, leftover raw materials during unloading of materials into mixing tanks, waste solvent from equipment cleaning using solvents, cotton waste from equipment cleaning, filter cartridges from un-dispersed pigments, pigment dust from air during unloading of pigment and emission of volatile organic compounds from open processing equipment (TGM for Integrated Paints Industry, 2010);all of which are not in the scope of this study.

The other waste streams related to this industry is waste paints which are mainly createdas consequences of paints contamination due to opening or burstingof paint containers. Waste paints produced as a result of paint containers damage accounts for about 70% of the total waste paint generation rate in a typical paint manufacturing industry. The damaged paints are then returned back to store for reprocessing or repacking otherwise for disposal at the expenses of the company. Other minor sources for waste paint in a typical paint industry include; spill of paints, off-specification paints and obsolete paint products (TGM for Integrated Paints Industry, 2010).

Spill of paints accounts for 5% of the waste paint generation rate in a given paint manufacturing industry. Spills are mainly due to accidental or inadvertent discharges usually occurring during transfer operations or equipment failures (leaks) in the production processes. Spills could also occur due to fire accidents though its occurrences are rare. In most cases, such spilled out waste paints are directly drummed and usually waiting for discharging to rivers during rainy season or for disposal.

Off-specification paints are created may be due to use of poor quality raw materials, failure to follow proper manufacturing process and negligence in implementation of on-process quality inspection, miss-tints, etc. Off-specification paints can be reworked into a primer or undercoat for sale to waste exchangers; and donation to volunteer and charity organizations. However, those off-specification paints which cannot be used or reworked back into manufacturing process or cannot be sold as a lesser grade product is usually stored in drums or tanks and sent offsite for disposal. According to data from selected paint industries, off-specification paints are estimated at 5% of the waste paint generation rate in a typical paint manufacturing industry.

Obsolete paint products are created as a result of changes in customer demand/customers returns, new superior products, and expiry of older paints due to long shelf life. It is also estimated at 20% of the total waste paints according to an assessment made in selected industries. As paints production exists, the generation of these wastes is inevitable with rate of generation varieswith the volume of production. Like other wastes, the final destinations of these hazardous substances are expected to be in the open environment, which leads to adverse environmental impacts such as air pollution through the release of volatile organic compounds (VOC's), land pollution, and surface and ground water contamination, etc.

Furthermore, there are no legal framework and industrial infrastructure to address the issues of waste paints collection, legal stockpiling, recycling and even disposing-off waste paints in an environmentally safe and sound manner. Besides, there is lack of knowledge in the sector with regards to environmental management especially on waste paint disposal and utilization.The main concern of this study is therefore to address the management solution for waste paintsfrom all sources mentioned to reduce its significant risks.

2.6. Management of Waste Paint

Sound chemicals management approaches and strategies can enable greater resource productivity through chemical recycling, recovery of valuable materials from the waste stream, energy supply and other innovations gains. Managing waste paints sustainably is critical due to relatively high volume of waste paints, expensive disposal process, and chemical constituents with high recycling potential. It is not only a cost effective solution for conserving energy and reducing the cost of disposal but also to assist the community and the environment through the reduction of greenhouse gas emissions. Several studies have been conducted globally to investigate recycling options for waste paint.

Modern waste management practices are moving towards material recycling. Similarly many researchers in waste paint management are also turning their research focus to identify solutions for recycling or reusing waste paints. In this research study, existing practices and solutions for waste paint management options were reviewed with emphasis made topaint reuse and paint recycling or valorizing.

2.6.1. Paint Reuse

The most environmentally sustainable options for waste materials is to reuse them in their original application. However, this is not always possible due to its associated technical restrictions and financial viability issues. In one way or the other, paint reuse can be achieved in four ways: paint swap, consolidation, remanufacturing and re-blending.

2.6.1.1. Paint Swap or Exchange

Paint swap is a process or an activity to donate the waste paints to a willing organization, friend, or local community for free instead to dispose it in the environment. This can theoretically become a highly efficient solution for waste paints management since it doesn't involve major transportation and does not require energy use for reprocessing. These programs, however, requires someone to manage the material, involve sorting out good quality paint, arranging paint into oil and latex types, and setting up an area where the public can view it. Hence, it could be labor intensive and therefore costly to be implemented.

2.6.1.2. Paint Consolidation

Paint consolidation is the process of combining waste paints that have similar characteristics into batches. Consolidation can be done at paints factory premises following collection events and at a small number of retailer shops. In this method, good quality paints is sorted based on the type of paints and other characteristics such as color. It is then filtered, poured into large container, and mixed (manually in most cases).

Consolidation produces medium grade, 100% recycled content paints that is available in limited colors. The advantages of paint consolidation are that it does not require expensive equipment or specially trained staff and that is why consolidation can easily be done at the point of collection. It is also effective in reducing storage and transportation costs since the bulked paints takes up less room than loose packed cans.

On the other hand, the primary disadvantage of paint consolidation is that it produces a product that has inconsistencies in color and performance and is therefore more suitable for applications where color matching and color choices are not a primary concerns. In some cases, paint consolidation can be used as a replacement for virgin paint with significant cost savings, example for painting of ware houses.

2.6.1.3. Remanufacturing of Paint

Paint reprocessing or remanufacturing is the process of converting waste paints into recycled content paint products that exhibit consistent color and performance characteristics. Paint reprocessing differs from paint consolidation in that reprocessing requires processing equipment, more experienced workers, and large volumes of waste paint. Therefore, it is generally not feasible to reprocess paints at the point of collection.

An advantage of reprocessed paints is that it is produced in various colors and is generally suitable for both interior and exterior applications. For many applications, reprocessed paints can be used as a replacement for virgin paints with significant cost savings. Another advantage is that reprocessed paints manufacturers often back the performance of their products. On the other hand, one of the disadvantages of using reprocessed paint is that it is generally available in a limited number of colors.

2.6.1.4. Paint Re-Blending

In this method, waste paints can be used as a minor constituent (less than 20 %) in the manufacture of "virgin" paints. The unusable paints are screened out and then sorted by characteristics such as type and color (Greiner et al., 2004). Consolidated paints can be used as a virgin paints replacement. The main advantage in this approach is that re-blending paints has the same consistency of color and performance as the virgin paints because of small amount of waste paints used. Issues such as possible bacterial contamination, intensive labor demand and quality assurance of final product exist for this approach, similar to remanufacturing paints option.

Also ongoing quality control is required for consolidated paints before blending it which adds up to the cost of this solution.The primary advantage of re-blended paints is that it is typically indistinguishable from virgin paints with respect to the consistency of color and performance because waste paints is a minor constituent.

2.6.2. Paints Valorization

In some cases, collected waste paints are blended into other products. Waste paints valorization refers to solutions where waste paints are used as a raw material for other products. Although many waste paints valorizing options are available and looks attractive at first, environmental impact and also financial viability and volume considerations of these options need to be assessed properly.

2.6.2.1. Concrete

One of the most commonly practiced options for WP is its application in the production of concrete. Generally WP can be used in concrete either as partial replacement for mixing water or as a partial replacement for virgin polymers used in certain types of concrete products. The main objective of WP valorization in concrete is to reduce water consumption. In addition to this, polymer latexes exist in WP could also prove to enhance concrete quality through exhibiting superior properties, such as smoother finish (Nehdi and Sumner, 2003; EPA Victoria, 2011). The use of these polymeric admixtures in concrete was not new. It dates back to 1920's (Ismail et al, 2011). It can beapplied in concrete by mixing either a polymer in dispersed, powdery, or liquid form with fresh cement mortar and concrete mixtures to increase the matrix bond between cement and aggregates to improve workability and flow of cementitious materials (Ismail et al., 2011).

Natural rubber was the first polymer used in PMC. In the 1960's the use of synthetic polymers such as Styrene Butadiene Rubber (SBR) was common (Clear and Chollar, 1978). Despite many advances in polymer admixture, the finished cost of produced concrete was still expensive and therefore its use was limited to certain applications (Almesfer et al., 2012). Such applications include but are not limited to bridge overlays, anti-corrosive linings, waterproofing, parking decks, and patching deteriorating concrete (Quiroz, 2011).

Recycling or valorizing waste paints as a replacement for polymer in Polymer Modified Concrete (PMC) can potentially make this product more cost effective and also preserves and improves the positive properties of PMC (Quiroz, 2011). The first application of waste paint in the concrete industry was reported in 1993 (Amazon Environmental Inc., 2013). In the following sections a number of research works and applications related to use of waste paints in concrete were reviewed.

- **Overlay, Rigid Pavement, Pervious Concrete**

Quiroz (2011) investigated two applications of WP: firstly the use of WP as a replacement for virgin latex in Latex Modified Concrete (LMC) and secondly, the possibility of improving properties of standard Portland concrete by using WP. Extensive series of tests have been carried out to evaluate quality and properties of WP concrete and compare it with those of standard concrete and SBRconcrete with regards to the following applications:

- Bridge Overlays: Possible replacement of Styrene Butadiene Rubber (SBR) which is commonly used as an admixture in this application has been investigated. For protecting the bridge super-structure from chemical attacks which may result in corrosion of the reinforcement and surface scaling of concrete, a thin protective layer is used on top of bridge roadway. Using WP in this application can reduce the cost of Latex Modified Concrete (LMC) enormously (Quiroz, 2011).

- Rigid pavements: High durability requirements are vital for rigid pavements and research has been conducted to investigate possible improvements of standard concrete properties using WP. Rigid pavements are used for places with constant traffic loading such as airports and highways (Quiroz, 2011).

- Pervious concrete: As demonstrated by Huang et al. (2009), latex additive improves tensile and compressive strength of pervious concrete. The possible use of WP as latex replacement was examined in Huang et al. (2009) work. Pervious concrete contains 15% to 25% air voids and is able to capture and reduce storm water, and recharge groundwater (Quiroz, 2011). Quiroz (2011) concluded that in all cases concrete produced by replacing WP succeeds to meet requirements and specifications. However, in some stages of the tests, concrete performance was found to decrease with addition of more WP which dictates proper investigation in mixture blending ratios.

- **Masonry Blockfill**

The application of WP in masonry blockfill mix was investigated, both as water replacement and standard polymer admixture replacement (Haigh, 2007). With this regard, several tests were carried out on fresh and hardened blockfill mix to compare its properties with conventional blockfill mixes.Polymer admixtures increase the workability and flow of cementitious materials and increase the matrix bond between cement and aggregates. These materials, however, are often too expensive (Haigh, 2007).

To understand the suitability of waste paints in masonry blockfill, the waste paints was sampled and tested at the paints collection factory to determine the variability of water, pigment and polymer content. It was established that using WP in blockfill mix can maintain the strength and improve the workability and can be used as a substitute for chemical polymeric admixtures currently used in the manufacture of concrete to attain similar results (Haigh, 2007).

- **Non-Structural Concrete Elements**

Nehdi and Sumner (2003) have investigated valorizing WP as both a partial replacement for virgin latex in Latex Modified Concrete (LMC) as well as a partial replacement for mixing water in footpath concrete. They concluded that use of WP results in comparative advantages such as increased flexural strength and decreased chloride ion penetrability. Nehdi and Sumner (2003) had also reported some observations about concrete produced for footpath (with 50% mixing water replaced with WP) constructed in 1998 and monitored till 2003 in Ontario, Canada.

The ease of construction, enhanced workability and finishing, distinctly lighter and more reflective color, not exhibiting coarse pop-outs, and no signs of surface scaling were amongst the advantages of this experimental sidewalk compared to a reference sidewalk. However they have suggested that more research is required before WP can be used in large scale industrial production of concrete for sidewalks (Nehdi and Sumner, 2003).

Mohammed et al. (2008) studied the use of WP as a partial water replacement in concrete. Different proportions of WP were added to concrete and were compared to virgin latex concrete. Results indicated that by adding WP, the properties of ordinary concrete improved and was comparable to regular LMC. WP was able to form a polymer film in concrete and its pigments and extenders fill additional porosity, which improves the long-term durability of concrete.

Moreover, WP had improved properties over the control mixture in compressive strength, flexural strength, and chloride penetrability. It was concluded that 15% WP partial replacement for water in concrete could be used in non-structural concrete elements such as sidewalk tiles, highway median barriers, and concrete blocks. Since WP can add beneficial properties to concrete compared to LMC, it can be used in special applications with greater economic benefit (Mohammed et al., 2008).

- **Concrete Car Park**

Toxfree (Chemsal) in Victoria, Australia has used waste latex paints as partial water replacement for concrete in a trial in their Victorian factory in Laverton North (EPA Victoria, 2011). The concrete produced passed all manufacturing tests and even showed superior properties compared to existing products in some aspects, such as in the final finish. Other benefits included 10% reduction in water consumption as well as saving 2% of natural resources used as composite material.

WP used for this purpose is separated from a mixed waste stream containing both latex and solvent-based paints which otherwise would be sent to concrete producers to be used as a fuel for cement kilns.From this qualitative assessment, one can draw the following generalized remarks to develop a successful waste paint management strategy.

Paints reuse which includes exchange, consolidation, re-manufacturing and re-blending is the most preferred approach in the life-cycle of waste paints if the technical and financial considerations are satisfied.

Paints exchange in the community results in returning high quality paint products to consumers and the community. However, its management system could be labor intensive and costly to be implemented. Producing low quality paints from waste paints (i.e. consolidation and remanufacturing) was seems to be a more reasonable approach and has been tried internationally. But the overall cost of recycling, sorting, filtering, removing bacteria, quality control and market development remains a barrier to this approach. Paint re-blending is also considered as a useful approach in producing paints of the same consistency in color and performance as virgin paints.

Issues such as possible bacterial contamination, intensive labor demand and quality assurance of final product exist for this approach also similar to that of paint remanufacturing. Hence, these technical difficulties in paint re-blending can affect the quality of the final product which will have adverse financial and market impacts. As a result, it has been a huge challenge for industry to follow the waste paint reuse program in a sustainable manner.

The second category of waste paints management options were valorization of waste paints in other products. Replacing water with waste paints in concrete has proven to be a technically and environmentally successful approach. Waste paints are also reported to be used as replacement for polymer and chemical additives in concrete, where the results of such works have been implemented and adopted in some countries. This review thus proposes the second option as a viable solution for waste paint management, which includes:

- Partial replacement for mixing water in Concrete; and
- Partial replacement for polymer in Polymer Modified Concrete (PMC) along with replacement of water, without affecting the quality of concrete.

Continuous investigations have been made to replace high cost virgin admixtures with low cost waste latex paints in concrete due to the similarities and functions of the active constituents in paints and virgin polymeric admixtures. In this case, the waste paints contributed in a similar form to virgin latex by exhibiting the same advantages in cementitious materials, such as increasing flexural strength and decreasing chloride ion penetrability.

The incorporation of waste paints in concrete can also be useful in maintaining environmental quality through stabilization and solidification of hazardous substances in the hardened concrete. Though large number of ingredients is present in the paints varieties, the primary constituents expected to occur in high volume and add value to concrete are discussed hereunder:

2.6.3. Surfactants

A surfactant or surface active agent is a substance that reduces the surface tension of a liquid. Surfactants are chemicals whose molecules have two parts of widely differing polarity and solubility (Porterm, 1994). If there is a problem in which two materials will not wet or make chemical contact with one another, surfactants can bridge the gap. An example of a commonly used surfactant is one with a hydrophilic (attracted to water) head and a hydrophobic (repelled by water) tail.

The opposing forces of the surfactant molecule ensure that the hydrophobic tail avoids a water medium by burying itself into whatever solid/polymer particle it can find, thus leaving the hydrophilic head hanging out suspending the particle in the water and repelling any further solid particles. Thus if enough surfactant is available, particles are encouraged to slide past and repel each other, rather than sticking together and reducing the dynamic of the system. The nature and proportions of the two parts of the molecule will vary between applications (Turner, 1988).

Many surfactants are active in producing foam, which can be desirable or undesirable depending on the application. For example household detergents contain surfactant, in which foam is desirable, whereas in the case of a cementitious material, the air entrained from foaming may be undesirable. In this case, individual air bubbles burst when they reach and pass through a surfactant-free liquid. However, in liquids containing surfactants, a surfactant film formed around the gas bubbles. If these bubbles reach the surface, which is also coated with surfactants, a lamella stabilized by the surfactant is formed (Evonik Tego Chemie GmbH, 2010).

2.6.4. Foam controllers

The easiest way to control foam is by choosing a suitable surfactant, although for many practical applications there will be limitations on the choice of surfactant, especially in the case of waste paints in which a broad range of surfactants are involved. In these cases there is a requirement for agents to control the foam. These are available and known as antifoams or defoamers. The terms are not synonymous, as antifoam prevents the build-up of foam, whereas defoamers cause the collapse of foam which has already formed. The working principle of foam controlling agents was that it emulsified into fine droplets, which must penetrate the surfactant film that stabilizes the foam lamella. The foam controlling agent then spreads into a lens at the liquid/air interface, destabilizing the foam lamella until the resultant film ruptures.

2.6.5. Thickeners

Thickening agents are active in paints to control the consistency and ensure that workability is maintained during storage and application. Thickening agents work through several methods, the most simple and common being thickeners which develop long chains which interact with particles rather than water, creating a loose network. Resinous thickeners and associative thickeners fall into this category. They bond to a wide variety of particles, including the latex particles, pigments, extenders, and in this case, cement particles. The bond they create is reasonably weak and can be broken as shear is applied, which explains the result of a higher initial yield shear stress.

Another type of thickener, which contain a lot of charged groups when neutralized with a base (e.g. fresh concrete) involve electrostatic interactions. These act in a similar way to the non-charged thickeners described previously. Other thickeners which are less common, although still very likely to be effective in the waste paint are known as hydro-dynamic volume exclusion thickeners and act in a very simple manner. They function purely to occupy volume and create obstacles, thus reducing the mobility of the surrounding particles.

2.6.6. Fine Fillers

Paint is made up of numerous types of small particles, with many in the range of 0.1μm to 10μm which are classed as fine and ultrafine materials. The source of fillers in paints is calcium carbonate, dolomite, diatomite, talcum, mica, silica sand, bentonite and pigments, etc. These ultrafine particles altogether accounts for about 25% of the solid mass of paints. The addition of fine particles and the application of particle packing theory allows a concrete producer to use poorly shaped or poorly graded sand and aggregates while still producing user friendly, workable concrete. The addition of fine particles can also contribute to increased workability.

The applications of fillers in the improvement of concrete properties have been investigated by different scholars. In 2003, an investigation was conducted by Lagerblad and Vogt with the intent of increasing the current knowledge of how ultrafine fillers (<10μm in size) act in concrete, based on earlier studies that had indicated that ultrafine material has a more profound effect on concrete properties than normal fillers. It had been determined that by incorporating large amounts of ultrafine fillers with reduced cement content, it was possible to produce a high strength concrete which implied a great potential for saving cement.

The types of fillers normally used in self compacting concrete (SCC) are less than 150µm is size. However due to the recent development of very effective super plasticizers, it is now possible to include large amounts of particles smaller than 10µm. These particles are referred to as ultrafillers, which increase the strength of concrete and act as a cement replacement. Lagerblad and Vogt found that it is possible to replace up to 40% of the cement and still obtain similar strength. The optimum effect was achieved when the cement is replaced but the water/cement ratio was kept constant. As a result the fillers increased the workability of the mix. The incorporation of fine fillers also accelerated the cement hydration, with the rate increasing with the fineness.

The total energy consumption of the mix containing ultrafine fine fillers is reduced but the use of such material is probably not economical for the bulk production of concrete. This is due to the cost of grinding and handling the fine material for concrete production. Meanwhile, ultrafine fillers remain ideally suited to special environments such as where there is interest in low energy release, dense concretes, special high performance concretes or other cementitious products where it is ideal to keep the amount of cement to a minimum (Lagerblad et al., 2003).

Bache (1981) described the strength and durability improvements available through the use of fine particle packing. Fine particle packing describes the geometric and kinematic principles for arranging larger bodies in a desired configuration which results in a highly dense structure. This formation results in significant increases in strength and durability obtained from the mechanical “locking” of larger aggregates together. The application of fine particle packing allows the use of a cheaper, rougher group of aggregates to produce a higher quality cementitious material at a lower cost (Bache, 1981).

In addition to this, Ferraris and Karthik (2001) reported on the role of fine powder additions and their effect upon the workability of cementitious materials. Previously accepted theory stated that the addition of mineral admixtures results in workability reduction, thought to occur due to the increased surface area of the fine particles exerting a greater water demand. Ferraris and Karthik provided support to an alternate theory that in specific cases the spherical particles easily roll over each other, in between the much larger aggregates, reducing inter-particle friction. In addition to this, they stated that the spherical shape also minimizes the surface to volume ratio, resulting in a low fluid demand.

2.6.7. Polymers

In paints, polymers make up the majority of the solid mass which accounts for about 26% of the total volume of paints by weight. This phase carries and then binds the other components of the paints such as the pigments and extenders, and then provides the continuous film forming component of the coating. Emulsion polymers are common in paint and are usually made up of water, monomers and surfactants.

2.6.8. Concrete polymer composites

Latex dispersions, which consist of small organic polymer particles dispersed in water, have been widely used to modify Portland cement-based concrete and produce what is commonly known as polymer-modified concrete (PMC) (Ohma, 1998; Van GemertD, et.al2004;, Nehdi M, Sumner J., 2003), with latex dispersions improving some undesired fresh and hardened cement properties such as cohesion, adhesion, brittleness, low flexural strength, and poor durability. Additionally, PMC is suitable for various structural and non-structural products and is ideal for overlay of pavements, bridges, and industrial applications (Gretz M, Plank J., 2011;, Aggarwal L.K, Thapliyal P.C, Karade S.R., 2007), due to PMC having a superior monolithic cement matrix in which the organic polymer phase and cement phase are interpenetrated and homogenized (Ohama Y., 2011;, Yang Z, Shi X, Creighton AT, Peterson MM., 2009).

The formation of the microstructure in PMC in relation to the polymer film formation being coincident with cement hydration is described by various authors and qualitative models (Ohma, 1998; Gretz M, Plank J., 2011; Beeldens A, Van Gemert D, Schorn H, Ohama Y, Czarnecki L., 2005).

Previous studies have indicated that the workability of PMC is enhanced due to surfactants from the latex dispersion being adsorbed onto the polymer and cement particles, generating a dispersing effect and an increase in entrained air, and also due to the “ball bearing” action of the polymer particles (Ohama,1998), while Lewis and Lewis (1990) reported that surfactants have a lubricating effect on the wet concrete mix, reducing the viscosity, and hence high workability of the cement paste is achieved at a much lower water to cement ratio. The action of the surfactants contained as emulsifiers and stabilizers in the polymer latex means that a large quantity of air is entrained in comparison to ordinary cement concrete.

However, excess air entrainment can be controlled with the proper selection and amount of latex and antifoaming agent used (Lamond JF, Pielert JH., 2006). Despite its improved flowability, PMC has improved resistance to segregation and bleeding due to the hydrophilic properties of the polymers and the air-entraining and water-reducing effects of the surfactants, and hence reductions in strength and waterproofness caused by bleeding and segregation are reduced in PMC (Ohama, 1998; Almesfer N, Haigh CJ, Ingham J., 2012).

Polymers in concrete are either incorporated in the cement-aggregate mix or used as a single binder, and can be divided into three classes: Polymer Modified Concrete (PMC), Polymer Impregnated Concrete (PIC), and Polymer Concrete (PC). The concrete polymer composite consists of two solid phases, being the aggregates which are dispersed through the materials, and the binder which consists of a cementitious phase and a polymer phase. Depending on the volume fraction of the polymer in the binder phase, the material shifts from PMC to PC (Gemert et al., 2005). Figure 2.1 below shows the system of classification of the concrete-polymer composites.

2.6.9. Polymer Impregnated Concrete (PIC)

The improvement of ordinary cement concrete by polymer impregnation requires fully or partially replacing all the air and water filled pores in the cement matrix phase with polymers. Low viscosity monomers are injected in the pores of the hardened concrete and subsequently polymerized, with the resulting polymers forming a second matrix of the pores and being interconnected throughout the concrete (Ohama, 2011). The concrete structure may be impregnated to varying depths or reside in the surface layer only, depending on whether increased strength and/or durability is to be improved (Blaga and Beaudoin, 1985).

The monomer, usually methyl methacrylate or vinyl, is polymerized by radiation or thermal catalytic techniques (Fowler, 1999). Since undergoing extensive research in the 1960's, the use of PIC has been limited, while Ohama (2011) mentioned that PIC, which was developed with great promise in the United States, Japan, and European countries in the late 1960's to 1970's, has nearly disappeared from the international construction industry because of its poor cost-performance balance.

2.6.10. Polymer Concrete (PC)

Polymer concrete (PC) is a composite material that is made by fully replacing the cement binder with polymeric binders consisting of liquid resins such as thermosetting resins, tar modified resins, and vinyl monomers. Most of the monomer systems for PC polymerize at ambient or room temperature, strongly binding the aggregates. In comparison with ordinary concrete, properties such as strength, chemical resistance, water-tightness, adhesion, and abrasion resistance are generally improved to a great extent with PC (Ohama, 2011).

PC's rapid curing and excellent bond to ordinary concrete and steel reinforcement make it a common repair material while PC overlays are used for bridge surfaces and floors in sports arenas due to fast curing and low permeability (Fowler, 1999). Although 3-5 times stronger than ordinary Portland cement concrete, PC displays brittle characteristics that have limited its usefulness for load-bearing applications, but its excellent strength and durability reduce the need for maintenance and frequent repairs (Reis, 2010).

2.6.11. Polymer Modified Concrete (PMC)

When latex is added to Portland cement concrete, the resultant composite is called PMC.Polymer latexes consist of small organic polymer particles ranging in size from 0.05- 0.5μm and dispersed in water. The formulations for emulsion polymerization of typical polymer latexes are listed below in Table 2.2. The latexes most commonly produced are copolymers of styrene-butadiene (SB), acrylates (PAE), styrene-acrylate (SA), polyvinyl acetate (PVA), and vinyl acetate ethylene (VAE), indicating that latexes are composed of organic polymers containing various monomers including styrene, acrylate, vinyl acetate, and butadiene (Walters, 2006).

Table 2.2.Formulations for Emulsion Polymerization of Typical Polymer Latexes as Polymer-based Admixtures (Ohama, 1998)

Type of latex	Material	Parts by mass
Vinyl acetate	-Vinyl acetate -Comonomer (butyl acrylate, ethylene, vinyl ester, of versatic acid) -Partially hydrolyzed polyvinyl alcohol -Sodium bicarbonate -Hydrogen peroxide (35%) -Sodium formaldehyde sulfoxylate -water	70.0-100.0 0.03-30 6.0 0.3 0.7 0.5 80.0
Acrylic copolymer latex	-Ethyl acrylate -A vinyl carboxylic acid -Non-ionic surfactant -Anionic surfactant -Sodium formaldehyde sulfoxylate -Caustic soda -Peroxide -Water	98.0 2.0 6.0 0.3 0.1 0.2 0.1 100.0
Styrene-butadiene copolymer latex	-Styrene -Butadiene - A vinyl carboxylic acid - Non-ionic surfactant	64.0 35.0 1.0 7.0

	-Anionic surfactant	0.1
	-Ammonium persulfate	0.2
	-Water	105.0

Polymer latexes are generally classified by the type of surfactant used to stabilize them, being either cationic (positively charged), anionic (negatively charged), or non-ionic (uncharged) (Ohama, 1998). During the latex manufacturing process (emulsion polymerization), the surfactants are added to the latex formulation to prevent coagulation of the particles from the mechanical stress of the process while it is necessary to incorporate an antifoam agent in the latex to control the air content as it is common for surfactants to foam when agitated (Walters, 2006).

2.6.12. Principles of Polymer Modification

The PMC has a monolithic cement matrix in which the organic polymer phase and cement phase are interpenetrated and homogenized (Ohama, 2011). While water is removed due to cement hydration and water evaporation, the polymer particles eventually coalesce into a continuous polymer film which is interpenetrated throughout the hydrated cement particles and subsequently results in coating the particles and aggregates. The principles of polymer modification process started with film formation in PMC which involves several steps, starting from an aqueous latex dispersion and ultimately resulting in a homogenous polymer film.

Generally the film forming process can be viewed as a succession of the four steps shown in Figure 2.1 below. While water is removed from the latex dispersion, ordering and packing of the polymer particles takes place, before an ordered array of hexagonal deformed latex particles is formed. Finally, a molecularly homogenous polymer film is formed as a result of polymer particle coalescence (Gretz and Plank, 2011). This film formation is governed by the polymer’s minimum film forming temperature (MFFT), which is the temperature below which the polymer particles will not coalesce to form a film. This MFFT will vary depending on the polymer and other additives used in the emulsion polymerization process, but typically range between 4-10^{o}C (Walters, 2006).

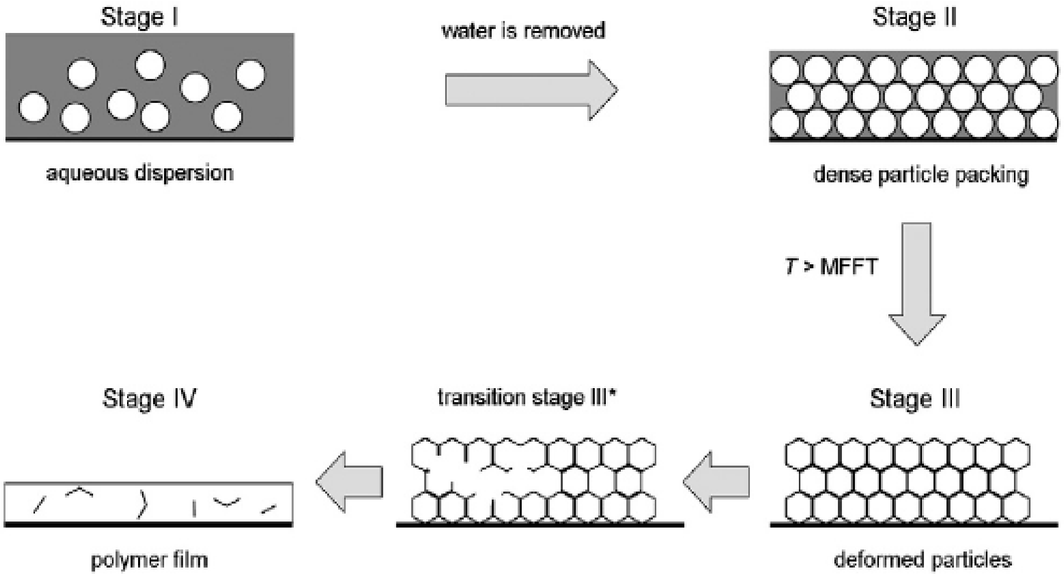

Figure 2.1.Process of Film Formation from an Aqueous Polymer Latex Dispersion (Gretz& Plank, 2011)

The polymer film formation process can simultaneously occur with cement hydration, especially in the case of dry curing conditions. Therefore partial or full encapsulation of the cement hydrates is possible, delaying the hydration process. In order for the cement hydrate and polymer phases to form a monolithic co-matrix, it is important that both cement hydration and polymer film formation proceed well and interpenetrate each other according to the simplified model shown in Figure 2.2 below, where the inclusion of aggregates in the matrix is shown. In PMC, aggregates are bound by such a matrix which results in superior properties compared with conventional cementitious composites (Ohama, 1998).

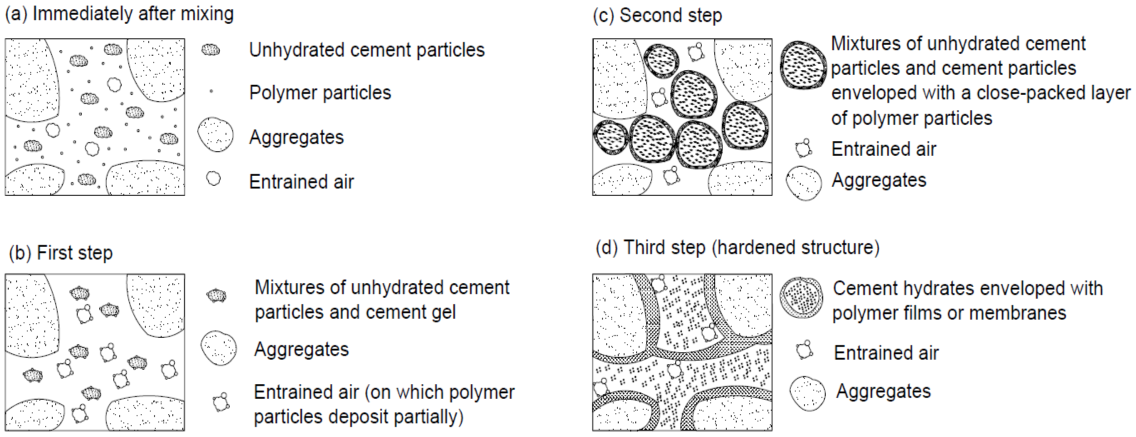

Figure 2.2.Simplified Model of Polymer-Cement Co-matrix Formation (Ohama, 1998)

Immediately after mixing, the cement and polymer particles are dispersed in water, with hydration of cement is occurring which results in an alkaline pore solution. A portion of the polymer particles is then adsorbed onto the cement grains and aggregates, with the polymer-cement ratio determining the amount of polymers present in the pore solution and aggregate surface. Some of the polymer particles may start to coalesce, which preferably takes place at the surface of a cement hydrate where extra forces are exerted on the polymer particles due to the extraction of water for cement hydration.

The following step consists of cement hydration and polymer coalescence, depending on the curing conditions. If a dry curing period is included, polymer film formation will take place earlier than if no dry curing period (low relative humidity) is introduced, which influence will cement hydration and strength development at early curing ages. The final step includes complete film formation and further cement hydration, with the polymer films being deposited at the interface of the aggregates and bulk polymer-cement phase, contributing to the elastic and final strength properties (Gemert et al., 2005).

The best conditions for strength development are a wet curing period to allow the cement to hydrate, followed by a dry curing period to promote polymer film formation. This process ensures that first cement hydration takes place with only limited film formation, followed by a larger amount of polymer particles being incorporated into the continuous film in the final stage. If the drying period is introduced earlier in the process, film formation will start earlier and proceed simultaneously with cement hydration, which will result in greater encapsulation of the cement hydrates and incorporation of the polymer phase in the hydration products that precipitate from the pore solution (Beeldens et al., 2005).

2.6.13. Properties of Polymer Modified Concrete

The addition of polymers to concrete generally improves the final product by allowing a reduction in the amount of water required in the freshly mixed concrete, and by providing dispersed polymers in the matrix of the hardened concrete (Walters, 2006).Ohama also describes the properties of polymer modified grout and concrete as being markedly improved over those found in conventional mix designs. The properties of fresh and hardened concrete are affected by a range of factors such as polymer type, polymer-cement ratio, water-cement-ratio, air content and curing conditions. However these can all be controlled to create the desired properties, which are outlined below.

2.6.13.1. Fresh properties of Polymer Modified Concrete

Workability

Ohama (1998) reported that PMC has improved workability due to the surfactants being adsorbed onto the polymer and cement particles, generating a dispersing effect and an increase in entrained air, and also due to the “ball bearing” action of the polymer particles. Lewis and Lewis (1990) reported that surfactants have a lubricating effect on the wet concrete mix, reducing the viscosity, and hence high workability of the cement paste in PMC is achieved at a much lower water to cement ratio compared to ordinary concrete.

These surfactants and polymers react in the same manner as do conventional water-reducers (super-plasticizers) added to concrete, helping to disperse the cement particles by reducing the inter-particle attraction, thereby reducing their tendency to clump together and requiring less water for the same workability (Grace Construction Products, 2007). Placement of the fresh PMC mixtures is markedly improved due to the plasticizing, lubricating, and air-entraining effects of the polymers and surfactants (Knapen and Van Gemert, 2009).

Air entrainment

The action of the surfactants contained as emulsifiers and stabilizers in the polymer latex results in a large quantity of air being entrained in comparison to ordinary cement concrete. Some air entrainment is useful to improve workability, but excess air will cause a reduction in strength andincreased susceptibility to freezing and thawing, which reduces durability (Ohama, 1998). Excess air entrainment can be controlled with the proper selection and amount of latex and antifoaming agent used (Walters, 2006).

Setting time

The cement hydration process is delayed by the polymer and the surfactants, which is visible in the strength development with the delay becoming more significant with an increase in polymer/cement ratio. The polymer film can partly or fully encapsulate a cement grain and hence reduce the hydration rate, while the cement hydration process is also influenced by the fact that the water is retained longer due to the presence of the surfactants at the surface of the polymer particles (Gemert et al., 2005).

Water retention

Concrete modified with polymers shows higher water retention than ordinary concrete due to the hydrophilic parts of the polymers attaching to the water molecules in the fresh mixture, preventing the dry-out phenomena by evaporation and absorption into the surrounding substrate or porous material (Knapen and Van Gemert, 2009). Ohama (1998) reported that the polymer latexes decrease water evaporation due to the filling and sealing effects of the impermeable polymer films formed, increasing the long-term strength.

Bleeding and Segregation

Despite its improved flowability, PMC has improved resistance to segregation and bleeding when compared to ordinary concrete, due to the hydrophilic properties of the polymers and the air-entraining and water-reducing effects of the surfactants, and hence reductions in strength and water proofness caused by bleeding and segregation do not exist in PMC (Ohama, 1998).

2.6.13.2. Hardened properties of Polymer Modified Concrete

Strength

Generally the compressive strength of PMC is lower than that of ordinary concrete after28 days, but equalizes or exceeds the compressive strength of ordinary concrete after

90 days due to the improved water retention. The tensile strength of the binder matrix is improved, as well as the adhesion strength between the aggregate and binder, which increases the flexural strength. At high relative humidity, the influence of polymer modification on short-term flexural strength is limited, but when a dry curing period is introduced, a polymer film starts to form in the binder phase and an increase in flexural strength is noticed with an increase in polymer/cement ratio (Beeldens et al., 2005). It is evident that optimum strength in PMC is obtained by achieving a reasonable degree of cement hydration when subjected to wet conditions at early stages, followed by polymer film formation under dry conditions (Ohama, 1998).

Bond and adhesion

Polymer bridges have been detected between the $Ca(OH)_2$ layers and bonding the layers together. The polymers improve the cohesion of the bulk cement paste, and hence a lower amount of micro-cracks is observed for PMC (Knapen and Van Gemert, 2009). It is this enhanced bonding properties that why PMC have used extensively for overlays on concrete bridges and garage decks (Walters, 2006).

Durability

Pores in PMC can be filled with polymers or sealed with continuous polymer films, reducing water absorption and permeability. Such good water impermeability provides high resistance to chloride ion penetration and reduced transmission of gases such as carbon dioxide (CO_2) and oxygen (O_2), which are all important factors in the corrosion of reinforcing bars in reinforced concrete structures (Ohama, 1998). The resistance of PMC against freezing and thawing is superior when compared to ordinary Portland cement concrete due to PMC's low permeability to water, while 30 years of field experience has not shown any freeze-thaw deterioration (Walters, 2006).

Drying shrinkage and creep

Generally the 28-day drying shrinkage of PMC tends to decrease with increasing polymer/cement ratio. The creep coefficient of PMC is considerably smaller than that of ordinary concrete, because of the strengthening of the concrete matrix with polymers, and the long-term strength development of PMC with improved water retention when compared to ordinary concrete (Ohama, 1998).

2.6.14. Optimum Curing Conditions for Latex Modified Concretes

Lewis and Lewis used the findings reported by Ohama on the optimum curing conditions for latex modified concretes and cements. Ohama stated that in order to achieve optimum compressive strength a reasonable degree of cement hydration under wet conditions at early stages must be allowed, followed by dry conditions to promote a polymer film formation due to coalescence of the polymer particles. Tests suggested that the time for each of these periods is two days of saturation, whilst the cement is undergoing the greatest strength development, followed by 26 days in which to complete the industry recognized 28 day period of dry curing. Development of compressive strength in latex modified concretes was observed to be high, despite the considerable length of the dry curing period.

The fundamental reasoning is that the polymer film formation, developed by the latex modifiers, exhibits excellent water retention and allows cement hydration to continue (Wang et al., 2005). Improved strength development was found to be one of the major advantages of latex modified concretes (Ohama, 1998).

2.6.15. Limitations on the use of concrete-polymer composites

It should be understood that one of the primary limitations on the use of concrete-polymer materials is cost, which can range from 10 to 100 times that of Portland cement, hence making its use for high volume applications impractical except in unusual cases where durability criteria render ordinary concrete unusable. Another limitation is the inability of PMC to withstand high temperatures, and hence PMC cannot be used as the structure for buildings housing people (Fowler, 1999). Rapid drying of PMC causes a skin (crust) to form on the concrete surface, which makes the finishing operation difficult. Hence care should be taken when relative humidity, wind, and temperature create an environment for rapid evaporation of water (Walters, 2006).

From the reviews made so far on the active constituents of paints, and the standard chemicals presently used as concrete admixture, conclusions can be made regarding the conceptual success of chemical replacement using waste paint. A primary ingredient in both conventional admixtures is surfactant, which covers a wide range of chemicals. Latex paint is almost always alkaline and contains amines similar to triethanolamine, as well as various other types of surfactant that are suitable for dispersing and stabilizing particles.

Many of the chemicals present in the paint will be inactive as a concrete admixture as they are present in minor concentrations that are only sufficient to serve their purpose when added to paint, whilst other chemicals are free to interact with cement. The polymers and surfactants found within waste paint have the potential to simulate the action of the calcium lignosulfonate as a hydration retarder.

In this study, the effects of waste paint on concrete was investigated in two stages; initially as a partial replacement for mixing water to establish if waste paint is a suitable additive for concrete mixing, and as partial replacement for virgin latex to understand the potential of waste paint as a replacement for conventional chemical admixtures. Concrete properties including, compressive strength and water absorption were evaluated for various mixtures and results are reported.

CHAPTER THREE

3. METHODOLOGY

The aim of this research is to undertake comprehensive study on waste paint valorization for concrete tiles production thereby reducing its environmental impacts. In order to effectively address this objective a qualitative research method was employed which helps to undertake experiments and conduct analysis through incorporating primary and secondary data.

Primary data requires the researcher to obtain information directly from the subject of study and this can be achieved through interviews, observation, original documentations and reports from company websites, archival records, physical artifacts and participation (Yin 1994). With this regard, information was collected through field visits for clarity and to learn facts. The visit was conducted within and outside the compounds of some selected industries to look at an indication of waste paint remnants in the vicinity. The production process in the industries was also observed in order to learn the instances of waste generation and final disposal of wastes.

While conducting interviews, the targeted respondents were factory owners, production managers, laboratory technicians, production foremen, sales attendants, storekeepers and casual workers in the industries. A total of 5 paint manufacturing industries in and around the city of Addis Ababa were targeted to respond to a set of open-ended interviews and the main information sought from these key respondents were on:

- Production capacities and attainable capacities;
- Waste paint management practices and estimated quantity;
- Sources of waste paints;

- Adopted disposal methods, etc.

Collecting of raw materials (waste paints) for specimen preparation was also conducted during this field visit program to specific industries. For secondary data, the researcher obtains information through reports, articles, including information from various sources that have been published (Ibid).

Finally experimental results and data collected both from primary and secondary sources were analyzed through qualitative descriptive analysis method. Tables, numerical figures, and percentages were used as the main techniques for analyzing and presenting of the data. Based on the findings, conclusions and recommendations were forwarded.

3.1. Materials

In this section, materials used in the experiments were described with respect to their sources and locations. In addition to this, materials and concrete specimen characterization test methods were mentioned with respect to national and international standards for comparison purposes. Determinant laboratory test results mentioned herein in the study both for materials and concrete specimens were carried out locally in the Ethiopian Construction, Design & Supervision Works Corporation, Research Laboratory & Training Center, DIL Paints factory central laboratory and Geological Survey of Ethiopia, Geochemical Laboratory Center.

3.1.1. Cement

Cement is a hydraulic binder which is used to produce concrete. In this study, Mugher Ordinary Portland Cement was used for casting of all concrete specimens. This cement is manufactured according to Ethiopian standard ES-1177-1-2005. Most ordinary Portland cements are useful in producing highly durable and sound concrete due to very low percentage of alkalis, chlorides, magnesia and free lime in its composition. This cement produces high heat of hydration as compared to Portland pozzolana cement which in turn contributes to strength development at the early ages of curing.

The chemical composition of this cement was analyzed as per ASTM C114 standards to check whether it complies with a typical hydraulic cementused forconcrete tiles production (Standard Test Method for Chemical Analysis of Hydraulic Cement; ASTM, 2004).

3.1.2. Aggregates

Crusher fines wereused in the experiment to produce concrete walk tiles which is supposed to make up the grain skeleton of the product. This product is selected among other varieties of aggregates in order to achievebetter smoothness of tiles. The rest of the cavities within this skeleton have supposed to be filled with sand and binder paste (cement) as complete as possible. This concrete aggregates together with sand sum up to approximately 80% of the concrete weight and 70% of the concrete volume. The type and quality of thismaterial is therefore vitally important for the properties of concrete, both fresh and hardened.

This aggregates quality in turn depends on the types of materials from which they are produced.With this regard, this material is produced through crushing of basaltic stonewhich are dense, free from deteriorated inclusions and surface pores. The grain size distribution of crusher fines used in this study was conducted per ASTM C136 standard specifications (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates; ASTM, 2004). This test is of high importance to design a reasonable combination of the different materials and their corresponding fractions in order to achieve a better compacted product.

3.1.3. River sand

Sand or fine aggregates shall consist of natural sand, manufactured sand, or a combination thereof. These fine aggregates shall be free of injurious amounts of organic impuritieswhich are deleteriously reactive with alkalis in cement and cause excessive expansion of mortar or concrete.

Taking this in to consideration, river sand used for the experiment was transported from one of the Ethiopian rift valley lakes. Sand from this locality were chosen with the assumption that the said deleterious substances possibly stick on its surfaces may be removed through the rolling effects of materials in the river valleys. Besides this, efforts were made to remove excessive silt/clay particles wherever it exists with the sand grain through washing before the commencement of an experiment.

Other undesired foreign materials such as vegetable matter were also avoided through sieving which otherwise prevent binder-aggregate bonding. Similar to crusher fines, the grain size distribution of river sand was done as per ASTM C136(Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM,2004).

3.1.4. Specific Gravity, Water Absorption and Unit Weight of Aggregates

These properties of aggregates should be determined in order to prepare a batch of concrete mix to produce tiles. The specific gravity of aggregates is a dimensionless value used to determine the volume of aggregates in concrete mixes. The determination of specific gravity of both crusher fines and sand was done according to ASTM C127 and ASTM C128 respectively (Standard Test Method for Specific Gravity and Absorption of

Coarse &Fine Aggregates; ASTM, 2004).The specific gravity was calculated at two different conditions which are dry condition and saturated surface dry condition. Only the dry specific gravity was used in preparation of the concrete mixes because all samples were oven dry.

On the other hand, absorption of aggregates is the weight of water present in aggregate pores expressed as percentage of aggregate dry weight. Similar for specific gravity, ASTM C127 was used to determine the absorption of crusher fines and ASTM C128 for fine aggregates (sand). The unit weight or bulk density of aggregate is the weight of aggregate per unit volume.

The bulk density value is necessary to select concrete mixtures proportions. ASTM C29 procedure was used to determine aggregates bulk density (Standard Test Method for Bulk Density ("Unit Weight") and Voids inAggregates;ASTM, 2004).

3.1.5. Waste Paints

Waste latex paints used in the experiment were collected from DIL Paints Factory, located in Oromia National Regional state, Gelan Industrial Zone. A total of 20 gallons (80 liters) of waste paints were collected to conduct the experiment. The collected samples were from two paint brands, DIL Mica and DIL Super paints, all of which are water based paints. The color of Mica paint was white and that of Super paints was off-white (broken white). The samples were collected in equal proportions, i.e., 40 liters from DIL Mica and the remaining 40 liters from DIL Super paints, each packed in 4 liters of paint cans or containers.

Up on collection, all paint cans or containers were opened and poured in to a large vessel or drum and manually mixed for homogenization. The homogenized paint was then characterized for some of its physical properties which include the determination of its solid content. This could be accomplished either through oven drying or in open air drying under laboratory conditions.

3.1.6. Pigments

Colored concrete is produced by the addition of pigmented metal oxides (mainly iron oxides). The pigments are in the form of powder, fine and low dust granulates. They are added at a levels of 0.5 – 5% of the cement weight; they must remain color-fast and stable in the alkaline cement environment.

3.1.7. Water

The suitability of water for concrete production depends on its origin. It must first be free from traces of oil and grease, foaming agents (detergents), suspended substances, odor,acid content ($pH \geq 4$) and humic substances which can affect concrete mix. Taking this in to consideration, only tap water supplied by the city Authority was used in the experiment for sand washing and concrete production.

3.2. Design of Mix Proportions

Mix proportions for the experiment were made on the basis of material volume calculation. The purpose of the calculation was to determine the quantity of major ingredients to prepare a batch of concrete mix. The calculation assumes that the designed quantities of cement, water, aggregate, waste paint and other additives add up to a volume of one batch of mix. Initial mix recipe for the mixture was adopted from literature review and from similar production programs undertaken in different parts of the country. However, mixture proportions used in this study was slightly amended based on the achievements gained in better product quality. An experiment was then proceeded to investigate the effect of WP as partial replacement for mixing water in concrete.

To produce concrete specimens, a control concrete mixture with a water-cement ratio (w/c) of 0.40 and mixtures with similar (w+WP)/c incorporating 10, 20, 30, 40, and 50% of WP were preparedto investigate the effect of waste paint (WP) as partial replacement for mixing water in concrete.

The proportions of all concrete mixtures investigated are shown in Table 3.1.The control mixture is typical concrete mix used in the production of municipal concrete tiles in Addis Ababa.

Table 3.1.Mixture Proportions

Inputs	**Reference Mixture**	**Waste Latex Paint, %**				
		10	**20**	**30**	**40**	**50**
Cement (kg)	100	100	100	100	100	100
Fine aggregate (kg)	126	126	126	126	126	126
Sand (kg)	180	180	180	180	180	180
Water (kg)*	40	36	32	28	24	20
Waste paint (kg)	0	4	8	12	16	20
w/c	0.40	0.40	0.40	0.40	0.40	0.40

1___________________

***Total water includes mixing water and water from WP or virgin latex.**

3.3. Mixing Procedures

The mixing sequence was as follows:

1. Raw materials for the mixture were prepared as per the pre-determined mix proportions achieved during trial production programs as indicated above in the Table.

2. The prepared raw materials were added to a steel drum mixer where dry mixing was done for a minimum of 1 minute to homogenize the materials prior to adding water.

3. The homogenized material was continued to be mixed for 1 minute with part of pre-determined mixing water.

4. Mixing of partially saturated materials was resumed again for 2 additional minutes with the addition of pre-determined water-waste paint blended compound until the mixture gets completely saturated. Final adjustment of the mixture would be made with the remaining part of pre-determined mixing water.

3.4. Specimens Preparation

Wet concrete mix made ready available for concrete tiles preparation was transferred from a mixer to wheel barrow from where the material was precisely weighed and feed to molds made of wooden formwork. The dimensions of wooden formwork used for concrete tiles production was (200x100x60mm) and rectangular in shape. After molded, specimens were subjected to table vibration for material spread in the box and compaction of the wet materials.

In this case, a total of 200 pieces of concrete walk tile samples of WP mixture in varying proportions (10, 20, 30, 40, and 50%) as partial replacement for mixing water were produced under laboratory conditions. In addition to this, 40 pieces of concrete walk tile specimens were prepared as a reference specimens without the addition of waste paints. All the specimens were then removed from a vibrating table and transferred to temporary curing area.

3.5. Curing

Protection of the prepared samples from premature drying is necessary so that strength development of the concrete is not affected by water removal. The consequences of too early water loss in concrete includes low strength in the parts near the surface, tendency to dusting, higher water permeability, reduced weather resistance, low resistance to chemical attack and reduced in size through shrinkage, etc.In order to minimize these effects and achieve better hardened concrete, several measures have to be undertaken to protect the fresh concrete particularly from premature drying due to wind, sun, low humidity and from extreme temperatures (cold, heat) and damaging rapid temperature changes, etc.

Taking this in to consideration, curing of all concrete specimens was undertaken under strict controlled conditions. Curing of the tiles was conducted in two distinct phases described herein as primary and secondary phases. Primary curing, whose purpose is to ensure that moisture is retained in the tiles, and not lost rapidly, was done for a period of two days. In this case, samples were covered with wet burlap and kept under shade were used with curing temperatures of 22-24 °C.

During this period, the products were showered with water twice a day to maintain slow curing of the specimens. In order to enable the tiles to further achieve strength, secondary curing was allowed to continue for another twenty-six days in open air. Compressive strength and water absorption tests for concrete walk tiles would be conducted at the ages of 7 and 28 days.

In similar fashion, a separate set of waste paint incorporated concrete mixtures were prepared to produce tiles on ‘a field condition’. In this case, tiles were produced by the use of hydraulic pressing machine currently used for casting of tiles on commercial scale. The percentages of WP used as partial replacement for mixing water for this experiment were also 10, 20, 30, 40 and 50% by dry weight. After casting of samples and completed its curing time, tiles were subjected to same tests as were done for those produced under 'laboratory condition'. The purpose of this test was mainly to determine the variations in compressive strength and water absorption of tiles due to compression of the hydraulic pressing machine.

3.6. Standard test methodsfor concrete walk tiles

There are standard tests which indicate the quality of concrete walk tiles by which it can be decided whether these tiles would be suitable to be used as construction materials or not. These tests include compressive strength, water absorption and flexural strength of tiles. Characteristics such as compressive strength and water absorption are the most important parameters for concrete walk tiles performance and thus they are selected as evaluation criteria in this research study.

3.6.1. Compressive strength of tiles

Compressive strength for tileswas conducted according to ASTM C902 method(Standard Specification for Strength and Absorption of Pedestrian and Light Traffic Pavement Tiles; ASTM, 2007). The load is applied up to one half of the expected maximum load, at any convenient rate, after which, the controls of the machine were adjusted so that the remaining load is applied at a uniform rate in not less than 1 or more than 2 min. The compressive strength is computed using equation.

$C= W/A$

Where,

C = compressive strength of the specimen, kg/cm^2.

W = maximum load, kgf.

A = average of the gross areas of the upper and lower bearing surfaces of the specimen, cm^2.

3.6.2. Water absorption of tiles

Water absorption for tiles was also carried out according to ASTM C 902 method(Standard Specification for Strength and Absorption of Pedestrian and Light Traffic Pavement Tiles; ASTM, 2007).According to this method tile samples were oven dried at 105°C for 24 h. After drying, the specimens were cooled at room temperature. The dry, cooled specimens were submerged, without preliminary partial immersion, in distilled water for 24 h. Then the specimen were wiped off the surface water with a damp cloth and taken the weight the specimen within 5 min after removing the specimen from the bath. Then, water absorption of the sample is calculated using equation.

Water Absorption, % = $100(W_s-W_d)/W_d$

Where,

W_d= dry weight of the specimen, and

W_S= saturated weight of the specimen after submersion in cold water.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In this chapter, raw material characterization test results were discussed with respect to their national and international standards. Mechanical tests on tiles was also discussed which are necessary to measure tiles properties upon which durability is dependent. These mechanical properties include compressive strength and water absorption as the results discussed hereunder.

4.1. Cement

As mentioned earlier, major oxides and minor constituents OPC was carried out per standard test methods and the results arepresented in Table 4.1 below.

Table 4.1.Chemical Composition of Mugher OPC

Mugher OPC composition		**ASTM C114 Standard (%)**
Oxides	**%**	
CaO	63.38	60-66
SiO_2	21.36	19-25
Al_2O_3	4.89	3-8
Fe_2O_3	3.74	1-5
MgO	1.74	0-5
Na_2O	0.16	0.5-1
K_2O	0.14	0.5-1
SO_3	2.48	1-3
LOI	1.25	1-2
Insoluble Residue	0.28	0.1-0.5
Free CaO	1.2	1-1.5

As shown in the table above, the oxide contents of OPC used in the experiment was within an acceptable range of international standards. The amount of MgO is also limited to an acceptable range as the presence of this oxide in ordinary Portland cement may cause the hydration of free MgO in concrete and results in the expansion of the hardened concrete. To control this detrimental expansion, MgO in composition is limited to 5%.

Same as free MgO, free CaO is undesirable due to the fact that these oxides hydrate much later than other compounds of cement. Besides, they show a large volume expansion after hydration resulting in disintegration of hardened concrete. So it should be within the standard limit as shown above in the table.

A test result of alkali oxides such as Na_2O & K_2O was also important for ordinary Portland cements which may promote alkali-aggregate reaction that may results in disruptive expansion. With this regard, the percentages of all minor constituents are within the standard permissible limits particularly for insoluble residue, loss of ignition and other compounds and impurities like, Sulphates, etc.

4.2. Crusher Fines

The purpose of conducting sieve analysis for crusher fines is to determine its grain size distribution by using a series of sieves. Aggregateswith greater than 4.75 mm in diameter areconsidered as coarse aggregates, whereas fine aggregates less than 4.75 mm in diameter. However, aggregates with respect to this study is limited to the finer part of aggregate (crusher fines), which is a combination of both fine and coarse aggregates.For such aggregate, sieve analysis was done according to standard methods as the results shown below in Table 4.2.

Table 4.2.Sieve Analysis of Crusher Fines

Sieve size (mm)	**Cumulative pass (%)**	**ASTM C136 Standard**
10.00	100	100
5.00	92.68	89-100
2.36	61.56	60-100

1.18	45.19	30-100
0.60	30.94	15-100
0.30	22.02	5-70
0.15	13.01	0-15

The sieve test result indicated that the grain size distribution of crusher fines is found to be within an acceptable range specified by international standards.

4.3. River Sand

Similar to crusher fines, the sieve analysis for river sand was done to determine the grain size distribution of materials used in the experiment. As per the test result, the gradation of river sand used in the study was fulfilling the grading requirements recommended by international standards as shown below in Table 4.3.

Table 4.3.Sieve Analysis of River Sand

Sieve size (mm)	Cumulative pass (%)	ASTMC136 Standard
9.50	100	100
4.75	96.55	95-100
2.36	90.09	80-100
1.18	79.83	50-85
0.60	51.75	25-60
0.30	20.73	5-30
0.15	8.03	0-10

4.4. Specific Gravity,Water Absorption and Unit Weight of Aggregates

As specific gravity,water absorption and unit weight of aggregates can affect the type and quality of concrete and as such parameters are input for mix designing, these parameters were tested both for crusher fines and river sand. The tested values are as shown below in Table 4.4.

Table 4.4.Physical Test results of Aggregates

Description	Crusher Fines		River Sand	
	Standard Range	Test Results	Standard Range	Test Results
Bulk Specific Gravity	2.70 - 2.90	2.77	2.0 – 2.60	2.60
Water Absorption (% by wt.)	0 – 0.5	1.42	2 - 7	7.0
Unit Weight (kg/m^3)	1250 - 1460	1485	1320 – 1680	1415

In the computation of quality for concrete mixes, it is the specific gravity of saturated surface dry aggregates that always used. The absorption capacity is a measure of the porosity of an aggregate expressed in percent by weight. It is also an important factor in designing our mix proportion. The unit weight /bulk density/ of an aggregate is the mass per unit volume in aggregate.

This unit weight is important for calculating the proportions of a concrete mix. With this regard, all the test values are within the specified requirements as shown in table above except for water absorption capacity of crusher fines, which is slightly higher than the standard range (0 – 0.5).

4.5. Waste Paints

A laboratory test was conducted at the central laboratory of DIL paints factory to determine the solid and water content for WP samples. The test involves oven drying of waste paint at a set of temperature (120^{0}c) for a specified period of time (4 h), which allows evaporating the liquid part of the paint. From this information, it is possible to calculate the solid content by deducting the water content from the initial mass of WP samples.

Latex of paints can also be recovered by pouring samples of WP in open containers and allowed to air dry in laboratory conditions (for a minimum of one month). The solid content is then determined as the difference between the initial mass of waste paint and the removed moisture content through evaporation. The test result of WP is summarized in Table 4.5 below.

Table 4.5.Physical Properties of Waste Paints

Properties	WP
Color	White & broken white
PH	8.1
Solid Content, %	51
Binder Type	Acrylic Resin
Density, Kg/m^3	1,034
Pigment Type	Titanium dioxide and extender fillers
Water Content,%	49

Source: Laboratory Test Result

From the table, one can see that, the paint had a mean density of $1{,}034 kg/m^3$ and was comprised of approximately 50% water, such that when water is replaced by waste paint the w/c ratio is proportionally reduced. The remaining solid content of the paint (about 51%) was composed of polymers and fine fillers. From paint formulations, one can recognize that the amount of fillers in typical water based paint is estimated at 25% (15% pigments & 10% extenders) of the total solid content.

These ingredients contain even a greater number of additives present to keep the paint stable and as required to serve its original purpose. Along with the polymers, it is this ingredient which will create changes in the way concrete is expected to behave with possibly drastic changes to air content, workability and concrete density.

4.6. Compressive strength

The compressive strength of specimens were tested by using compression testing machine on tiles of a control mixture and on other concrete products incorporating different proportions of WP. The tests were carried out at the ages of 7 and 28 days based on ASTM C902 standard methods for the purpose of making comparison with standard tiles (made without waste paint). According to ASTM C902 standard specifications, tiles to be used for pedestrian and light traffic purposes should have a minimum compressive strength of 20.7 MPa at the age of 28 days (Annual book of ASTM standards, 2007). Based on this, the test results of concrete specimens were presented in table 4.6 below for comparison with the standard specifications.

Table 4.6.Compressive Strength of Tiles

Mixture	Compressive Strength (MPa)		ASTMC902 Standard (28 days)
	7 days age	28 days age	
Reference	24	26	20.7
10% WP	22	27	
20% WP	21	25	
30% WP	20	24	
40% WP	19	23	
50% WP	18	22	

As shown in Table 4.6 above, the 7-day compressive strength results indicated that the reference mixture had developed a greater compressive strength (24 MPa) than all the mixtures containing WP in the proportions of 10-50%. The result suggests that an increase in the proportion of WP in mixtures delayed or retards the strength development of concrete.

Although, the compressive strength of all concrete mixtures containing WP increases at the age of 28 days, still concrete mixture containing the highest proportion of waste paint (50% WP) reveals a lower compressive strength (22 MPa) than other concrete mixtures containing lower proportion of WP (27 MPa). But, the test results of all mixtures had exceeded the minimum strength requirements set for pedestrian and light traffic pavement tiles at the age of 28 days.

Moreover, concrete mixtures containing WP in the proportions of 20-50% by weight of mixing waste paint have showed a lower strength development than the control mixture at the age of 28 days. This is also either due to the retarding effects of paints or increase invoid spaces of concrete.On the other hand, a 10% addition of WP in mixture has shown a positive effect on the strength of concrete at the age of 28 days, even shows a better result than the reference mixture. The result indicated that this proportion is the optimum dosage of paint to be used as partial replacement for mixing water in concrete.In addition to this, waste paints in less proportion to 10% show no change on the performance of tiles as compared to the reference mixture.

The general trend in decrease and increase in the compressive strength at 7 and 28 days respectively is due to the formation of polymer film in the hardened concrete. Moreover, polymers require time for the development of polymer structure and formation of Portland cement matrix. This polymer film matures with age; this is the reason that at 28 days of age, increase in compressive strength is registered with the addition of 10% WP. However, at 7 days, the development of polymer structure and cement hydration is in process of formation, consequently the effect of WP addition on compressive strength is negative.

The test results of samples produced by the use of hydraulic pressing machine in general reveals an improved compressive strength than those produced under laboratory conditions, due to the compression pressure. The strength test results of hydraulically produced specimens were presented in appendix-A (Table 2A).

4.7. Water Absorption

Water absorption values of mixtures with different dosages of WP have shown in Table 4.7 below along with values of the control mixture. The water absorption test was conducted based on standard specification of ASTM C902, which states that the maximum water absorption of tiles to be used for pedestrian and light traffic purpose should not be exceeded14%by weight.

From the table below, one can see that the water absorption of a control mixture was higher both at the 7 and 28 days of age (13 & 11% respectively) when compared with mixtures incorporating different proportions of WP. However, the water absorption was reduced uniformly with the increase in proportion of WP in the mixture both at the age of 7 and 28 days.

Table 4.7.Water Absorption of Tiles

Mixture	**Water Absorption (%)**		**ASTMC 902 Standard (28 days)**
	7 days age	**28 days age**	
Reference	13	11	14
10% WP	10	8	
20% WP	8	6	
30% WP	7	5	
40% WP	7	5	
50% WP	6	5	

The decrease in water absorption of latex modified concrete containing 10%, 20%, 30%, 40% and 50% WP at the age of 28 days is due to the formation of polymer film which makes the concrete water tight.

The results about water absorption of control and LMCs clearly depict that with increase of age, polymer film is formed which results in reduction of water absorption of concrete.Based on the standard specifications stated in ASTM C902, all the test results for water absorption of tiles are below the maximum recommended limit.

Like to the compressive strength, the water absorption of tiles produced with the use of hydraulic pressing machine was improved when compared with tiles produced under laboratory conditions, also due to the compression pressure. The absorption test result of specimens produced by hydraulically pressing machine is presented in Appendix-A (Table 4A).

CHAPTER FIVE

5. ENVIRONMENTAL ASPECTS OF WASTE PAINTS IN CONCRETE

This section provides an overview of the major environmental aspects associated with valorizing WP in concrete.

5.1. Positive Environmental Aspects of WP in Concrete

a) Water Conservation

Using large amounts of fresh water is an important issue in concrete industry. The mixing water requirement for concrete industry and curing concrete is estimated at millions of tons. According to this study, about 142 kg of fresh water is required to prepare one cubic meter (m^3) of concrete. If 10% of this mixing water is replaced with WP, it is possible to save 14 kg of water per cubic meter of concrete. Thus, replacing water with WP can save thousands of tons of water per year.

b)Reduce Greenhouse Gases

Concrete generates a large amount of greenhouse gases and require a large amount of raw materials such as limestone and clay, and fuel such as coal, resulting in deforestation and top soil loss (Mehta, 2001). The worldwide concern and governance on carbon dioxide emissions has encouraged research into the partial replacement of cement, polymer, aggregates with supplementary materials such as WP, fly ash and slag.

According to European Federation of Concrete Admixture's Environmental Declaration Super plasticizing Admixtures (Sjunnesson.J, 2005) the manufacturing of one kg of super plasticizers or concrete admixtures produces 2 kg of carbon dioxide (CO_2). However, Using WP in concrete helps to reduce the carbon footprint by reduction in the amount of virgin polymer required for PMC. Hence, by valorizing 14 kg of waste paint per cubic meter of concrete, there is a possibility to reduce 28 kg of greenhouse gases emitted to the atmosphere.

c) Reduce Energy Consumption

Concrete is one of the most energy consuming materials in the world. Swamy (2000) stated that cement and chemical admixtures are valuable resources in concrete but they are energy intensive. According to this study, the manufacturing of every kg of chemical admixture requires about 4 to 7.5 MJ of energy. However, using WP in concrete also helps to save energy and material by reduction in amount of virgin polymer required for manufacturing PMC. Hence, by valorizing 14 kg of waste paint in one cubic meter of concrete, it is possible to save about 56MJ to 105MJ of energy.

d)Reduce use of virgin materials (e.g. by Increasing Concrete Durability)

Increasing concrete durability is the other major step towards the sustainable development of concrete (Swamy, 2000). Creating a longer design life for concrete will end up in saving resources and energy and in cutting carbon emission. The service life of pavement for instance, is between 15 to 20 years.

Current studies suggest that by valorizing WP in rigid pavement concrete, the service life will increase to 30 to 40 years (Quiroz, 2011). Production of concrete can be reduced remarkably as a result of increasing the service life of concrete. This consequently leads into great savings in concrete consumption and thus reduces the amount of resources, energy and water that would otherwise being used for concrete production.

5.2. Potential Negative Environmental Aspects of WP in Concrete

Using WP in concrete can be a great move toward a sustainable future, however there are some concerns regarding the environmental impact of using WP in cement-based materials including the potential for leaching of the heavy metal ingredients in WP during the concrete life cycle.

Recycled materials such as WP used in applications such as facades, foundations, embankments, road works and etc. are subject to environmental conditions such as rain and consequently their contaminant emissions need to be determined (Disfani et al., 2012). This can be assessed by leaching tests which provide the basis for defining the life cycle of recycled materials within a given time period (Valls and Vasquez, 2002 in Disfani et al., 2012). For each application of recycled material the leachable concentration limits are necessary to limit the potential for leaching of contaminants from waste/recycled material which will remain as a construction material for a long period of time (EPA Victoria, 2009 in Disfani et al., 2012).

WP may include biocides, heavy metals and solvents such as ethylene glycol and glycol ethers (Nehdi and Arif, 2010). Nehdi and Aref (2010) investigated the impact of using WP in concrete on itsenvironmental performance. The leachability of WP concrete was tested under various exposureconditions such as freezing–thawing and wetting–drying cycles in fresh and salt water in thelaboratory.

Results of this study showed that the heavy metal leachate from 15% and 25% WPconcrete products were completely within the acceptable range enforced by US EPA hazardouswaste regulations (Nehdi and Arif, 2010).Since the optimum dosage of WP used to produce concrete walktileswith respect to this study was10%by weight of mixing water,it isbelow the amount used in the previous studies. Hence, the heavy metal leachate from such concrete products is supposed to be within the acceptablerange of hazardouswaste regulations.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The addition of waste paint in to concrete used for side walk tiles has adverse effects on its compressive strength if it is added in greater proportions. However, a 10%WP addition in concrete reveals a positive result as compared to the reference mixture. The decrease in compressive strength of tiles with increase in volume of waste paint is attributed either to the retarding effects of paints or an increase in void spaces in concrete due to the foaming effect of paints.

On the other hand, the water absorption of concrete walk tiles decreases uniformly with the increase of WP proportion as partial replacement for mixing water when compared to the control mixture. This implies that latex modifiers contribute significantly to the reduction in water absorption due to polymer film formation which makes the concrete water tight**.**

In addition to this, a 10% replacement of mixing water with waste paint saves an estimated amount of 14 kg of fresh water per cubic meter of concrete used for tiles production. Again by valorizing 14kg of waste paint per cubic meter of concrete, an estimated amount of 28kg and 56-105MJ of CO_2 and energy can be reduced respectively by reduction in the amount of virgin polymer required for PMC.

Reducing the use of virgin materials by increasing concrete durability is also the other advantage of using waste paint in concrete. WP in this case enhances the mechanical properties of concrete thereby creating longer design lifewhich ends up in saving resources, energy and in cutting carbon emission. The output of this study thus indicates that recycling waste paint in concrete is found to be viable both in managing waste paint and add value to the products.

Hence, it can be concluded that waste paint has the ability to replace standard chemical admixtures and part of mixing water in concrete without affecting the mechanical properties of tiles provided that the optimum dosage of paint is not exceeding 10% by weightof mixing water. With this recommended dosage, the leachability of WP concrete products is expected to be within the acceptable range of hazardouswaste regulations.

6.2. Recommendations

1. In addition to use waste paint in the production of non-structural concrete such as pavement tiles, further investigations are recommended to promote & undertake study on the possible use of this commodity in structural concrete (masonry works) to fully utilize large volume of waste expected to be generated with the growing economy.
2. The variation of polymer types in paints and their possible influence on the characteristic properties of cementitious materials have also needed further investigation which helps to set up a stable national average in material quality, given a variety of paints are collected.
3. Awareness creation should be done among paint producers to donate their waste paint to concrete manufactures even for free instead of disposing in the environment at considerable economic cost.

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APPENDIX-A

Table 1A: Strength Test Results of Specimens Produced Under Laboratory Conditions

Mix code	**Specimen No**	**Test result at 7 days (MPa)**	**Test result at 28 days (MPa)**
RM00	1	24.98	26.69
	2	25.38	26.29
	3	22.04	25.44
	4	24.85	27.59
	5	23.89	25.49
Average Result		**24.23**	**26.30**
WP10	1	21.27	27.09
	2	21.74	26.59
	3	22.12	25.44
	4	22.15	28.54
	5	23.45	28.94
Average Result		**22.15**	**27.32**
WP20	1	21.02	23.14
	2	22.04	28.39
	3	20.22	23.39
	4	21.33	24.89
	5	22.04	27.44
Average Result		**21.33**	**25.45**
WP30	1	20.92	25.59
	2	20.33	24.24
	3	21.12	20.24
	4	20.07	25.84
	5	19.07	25.49
Average Result		**20.30**	**24.28**
WP40	1	20.64	29.14
	2	18.15	21.29
	3	19.40	18.84
	4	18.25	17.04
	5	17.99	31.09
Average Result		**18.89**	**23.48**
WP50	1	18.66	24.14
	2	18.25	20.24
	3	17.69	23.39
	4	18.66	23.34
	5	17.97	21.34
Average Result		**18.25**	**22.49**

Table 2A: Strength Test Results of Specimens Produced by Hydraulic Press Machine

Mix code	Specimen No	Test result at 7 days (MPa)	Test result at 28 days (MPa)
RM00	1	25.44	28.19
	2	25.31	27.53
	3	26.24	27.94
	4	27.13	28.91
	5	25.32	27.94
Average Result		**25.89**	**28.10**
WP10	1	21.99	29.55
	2	23.71	28.11
	3	25.32	28.32
	4	23.55	28.97
	5	23.88	30.87
Average Result		**23.69**	**29.16**
WP20	1	23.00	25.76
	2	25.98	30.11
	3	24.28	25.75
	4	22.98	25.19
	5	22.99	29.94
Average Result		**23.85**	**27.35**
WP30	1	23.82	27.52
	2	22.65	26.29
	3	23.24	24.36
	4	21.92	27.64
	5	20.10	28.15
Average Result		**22.35**	**26.79**
WP40	1	22.37	30.19
	2	20.45	23.24
	3	22.49	23.14
	4	19.96	22.84
	5	19.34	32.00
Average Result		**20.92**	**26.28**
WP50	1	20.54	26.25
	2	19.85	22.86
	3	20.12	25.89
	4	19.32	25.85
	5	19.32	22.84
Average Result		**19.83**	**24.74**

Table 3A: Absorption Test Results of Specimens Produced Under Laboratory Condition

Mix code	Specimen No	Test result at 7 days (%)	Test result at 28 days (%)
RM00	1	11.64	8.48
	2	13.60	10.31
	3	11.32	10.49
	4	15.14	11.16
	5	14.97	14.57
Average Result		**13.33**	**11.00**
WP10	1	9.94	8.32
	2	10.98	8.81
	3	10.64	8.24
	4	10.47	7.76
	5	9.45	8.19
Average result		**10.30**	**8.26**
WP20	1	8.22	6.13
	2	7.08	5.96
	3	9.53	6.49
	4	8.33	6.92
	5	7.14	5.09
Average Result		**8.06**	**6.12**
WP30	1	8.73	5.69
	2	6.71	4.52
	3	7.10	3.45
	4	6.20	5.59
	5	7.38	6.92
Average Result		**7.22**	**5.23**
WP40	1	6.55	5.69
	2	7.02	5.33
	3	8.70	4.38
	4	6.45	6.84
	5	7.26	4.19
Average Result		**7.12**	**5.29**
WP50	1	7.10	6.98
	2	5.69	4.18
	3	6.33	5.91
	4	6.85	5.45
	5	5.52	4.31
Average Result		**6.30**	**5.37**

Table 4A: Absorption Test Results of Specimens Produced by Hydraulic Press Machine

Mix code	Specimen No	Test result at 7 days (%)	Test result at 28 days (%)
RM00	1	8.23	5.11
	2	9.98	8.56
	3	10.23	8.87
	4	12.57	8.11
	5	10.77	9.98
Average Result		**10.36**	**8.13**
WP10	1	8.34	7.39
	2	8.56	8.01
	3	9.90	7.65
	4	8.57	5.34
	5	7.14	6.10
Average Result		**8.50**	**6.90**
WP20	1	7.20	5.98
	2	6.00	5.23
	3	8.34	5.40
	4	7.99	5.82
	5	5.98	4.99
Average Result		**7.10**	**5.48**
WP30	1	7.91	5.12
	2	6.11	4.00
	3	5.88	3.11
	4	5.98	5.32
	5	5.23	4.89
Average Result		**6.22**	**4.49**
WP40	1	6.12	5.00
	2	5.82	4.83
	3	6.34	4.41
	4	4.54	4.13
	5	6.22	3.89
Average Result		**5.81**	**4.45**
WP50	1	6.54	5.34
	2	5.11	3.99
	3	5.87	5.12
	4	5.34	4.11
	5	4.98	3.87
Average Result		**5.57**	**4.49**