PERFORMANCE OF POLYMER MODIFIED CONCRETE INCORPORATING POLYVINYL ACETATE WASTE

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Special dedication to my parents

Haji Noruzman bin Haji Mohamed Sam and Hajah Wan Paziah Binti Wan Abdul Manan

To my greatest supporters

Hambali Bahri, Ain Suhara, Ainie Hayati, Azizul Hafidz and Wan Mohd Aidid Daniel Hasbollah

And also to all who supported me by Doa and work. Thanks for everything. May Allah bless you. Amin

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ABSTRACT

Generation of waste latex paint (WLP) from the manufacturing process of binder paint products is increasing globally due to the increasing need for aesthetical features in association with rapid industrialisation and urbanisation. The volume of waste generated in the form of solids and effluents from these productions annually cause not only financial burden, but accountable for future environmental consequences. The use of polymers such as natural rubber, acrylic, and styrene-butadiene latex has been acknowledged of their characteristics to influence the properties of concrete. In spite of the various researches conducted on the study of polymer in concrete, very little information is known about the incorporation of WLP consisting of polyvinyl acetate waste (PVAW) generated from the binder paint industries. This research aimed to investigate the effect of utilisation of PVAW as an admixture to improve the properties of concrete. The fundamental analysis of WLP was determined including ICP-MS, GPC, DSC, and FTIR. The properties of fresh state concrete include setting time, workability, and heat of hydration. The tests were carried out on mechanical properties of hardened concrete such as compressive, tensile, and flexural strength. The durability test was conducted to investigate the chemical resistance in acids and sulphate solutions, elevated temperature, water absorption, drying shrinkage and leaching test. The microstructural tests in terms of XRD, FESEM, and MIP were also studied. The properties of WLP in terms of the chemical and physical were studied and compared with original latexes. The finding showed that incorporating PVAW impacted positively on the workability of concrete and reduce temperature rise in mass concrete. The setting time of the modified cement paste was delayed compared to the control specimen. However, the delayed setting time was within the limit as suggested by the relevant standard. While in hardened state properties, it shows that optimal compressive strength was achieved from the incorporation of 2-3% PVAW in concrete. Both tensile and flexural strength were larger than the strength of control concrete from the addition of 5% and 1% PVAW, respectively. Better performance in flexural strength was observed in the reinforced modified concrete beam. Modified concrete showed a decrease in water absorption with increase of the PVAW addition. The research examined various aspects of the durability of concrete against physical and chemical attacks. However, it demonstrated slightly less performance to destructive chemicals and elevated temperature. Meanwhile, the incorporation of polymer up to 10% PVAW had no significant effect of heavy metal ion mobilisation in leaching test. It can be concluded that the incorporation of PVAW in concrete may give better performance in strength and durability of the concrete as well as able to minimise the PVAW waste disposal from the production of binder paint for a sustainable environment.

ABSTRAK

Penjanaan sisa cat lateks (WLP) daripada proses pembuatan produk cat pengikat semakin meningkat secara global disebabkan oleh peningkatan keperluan ciri-ciri estetika seiring dengan peningkatan urbanisasi dan industrialisasi yang pesat. Janaan sisa pepejal dan efluen yang dihasilkan secara tahunan ini, telah menyebabkan masalah bukan sahaja dari segi kewangan tetapi juga kepada alam sekitar. Penggunaan polimer seperti getah asli, akrilik, dan stirena-butadiena lateks telah diakui cirinya dapat mempengaruhi sifat-sifat konkrit. Walaupun pelbagai kajian telah dijalankan ke atas polimer konkrit, namun tidak banyak yang diketahui tentang penambahan WLP yang mengandungi sisa polivinil asetat (PVAW) daripada hasil buangan industri cat pengikat. Oleh itu, objektif kajian ini adalah untuk mengkaji kesan penggunaan PVAW sebagai bahan tambah bagi menambah baik sifat-sifat konkrit. Analisis asas WLP telah dilakukan termasuk menggunakan ICP-MS, GPC, DSC, dan FTIR. Sifat konkrit segar yang dikaji adalah masa pemejalan, kebolehkerjaan, dan haba penghidratan. Ujian terhadap sifat mekanikal pula adalah kekuatan mampatan, tegangan, dan lenturan. Ujian ketahanlasakan turut dijalankan untuk mengkaji rintangan kimia dalam larutan asid dan sulfat, peningkatan suhu, penyerapan air, pengecutan kering dan ujian pengurasan. Ujian struktur-mikro menggunakan XRD, FESEM, dan MIP juga dikaji. Selain itu, ciri-ciri WLP dari segi kimia dan fizikal juga diuji dan dibandingkan dengan lateks asal. Hasil kajian menunjukkan dengan penambahan PVAW boleh memberi kesan positif terhadap kebolehkerjaan konkrit dan merendahkan peningkatan suhu dalam jisim konkrit. Didapati bahawa masa pemejalan adalah lebih lama bagi simen yang diubahsuai berbanding dengan spesimen kawalan. Namun begitu, masa pemejalan bagi simen yang diubahsuai masih dalam lingkungan piawai. Bagi konkrit yang berada dalam keadaan keras, didapati kekuatan mampatan optimum tercapai dengan pencampuran 2–3% PVAW. Kekuatan tegangan dan lenturan konkrit adalah lebih tinggi berikutan dengan penambahan sebanyak 5% dan 1% PVAW berbanding kekuatan konkrit yang asal. Didapati rasuk konkrit bertetulang yang telah diubahsuai menunjukkan prestasi yang baik dalam ujian lenturan. Konkrit yang diubahsuai menunjukkan penurunan dalam penyerapan air dengan peningkatan penambahan PVAW. Daripada segi aspek ketahanan konkrit terhadap serangan fizikal dan kimia, didapati konkrit yang mengandungi PVAW menunjukkan prestasi yang agak lemah dalam menangani serangan kimia perosak dan ujian peningkatan suhu tinggi. Sementara itu, penambahan sehingga 10% PVAW tidak mempunyai kesan ketara dalam mobilisasi ion logam berat dalam ujian pengurasan. Kesimpulannya, penambahan PVAW dalam konkrit mampu menghasilkan konkrit yang lebih kuat dan tahanlasak disamping dapat meminimumkan pelupusan sisa PVAW hasil daripada pengilangan cat pengikat untuk persekitaran yang mampan.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
ACI	-	American Concrete Institute
CSH	-	Calcium silicate hydrate
C_3S	-	Tricalcium silicate
C_2S	-	Dicalcium silicate
C_4AF	-	Tetracalcium aluminoferrite
$Ca(OH)_2$	-	Calcium hydroxide
PMC	-	Polymer modified concrete
PMM	-	Polymer modified mortar
PVAW	-	Polyvinyl acetate waste
LMC	-	Latex modified concrete
LMM	-	Latex modified mortar
TGA	-	Thermogravimetry analysis
SEM	-	Scanning electron microscopy
MIP	-	Mercury intrusion porosimetry
EDX	-	Energy dispersive x-ray
UPV	-	Ultrasonic pulse velocity
XRD	-	X-ray diffraction
XRF	-	X-ray fluorescence
FTIR	-	Fourier transform infrared spectroscopy
DSC	-	Differential scanning calorimetry
WLP	-	Waste latex paint
VAW	-	Vinyl acetate effluent

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CHAPTER 1

INTRODUCTION

1.1 Introduction

There is an increase of global concern on the environment demand that waste should be appropriately managed in order to minimise or possibly eliminate the harmful effect towards the environment. Due to ever-increasing quantities of waste materials and industrial by-products generated, solid waste management becomes a primary concern in the world (Siddique and Singh, 2011).

The establishment of a growing diverse manufacturing sector in Malaysia has contributed immensely to the advancement of the Malaysian economy. This development is key to the observable relative rapid economic growth of the country (Rashid *et al.*, 2010). Malaysia's economy has transformed since the 1970s from agriculture based economy into emerging an industrial manufacturing entity (Mokhtar *et al.*, 2010). According to (Aja *et al.*, 2016), the manufacturing sector in 1966 contributed 11% the nation's gross domestic product (GDP), 24% in 1988, and 24.6% in 2010 and while in 2012, the manufacturing sector contributed 24.2% to the Malaysian GDP. The chemicals industry is the second largest contributor to total manufactured exports, amounting to about 6% of the total Malaysian exports annually. The manufacturing of chemicals, including the manufacturing of refined petroleum products, vegetable and animal oils and fats; basic chemical, fertilisers including nitrogen compounds; plastics and synthetic rubber in its primary form, contribute 13.5%, 12.4% and 6.8% to GDP respectively (Abdullah, 2008). The rapid industrial growth and urban development in the country have contributed to a significant rise in the volume as well as a variety of toxic and hazardous waste being generated annually (Abdullah, 1995; Saeed *et al.*, 2009). In a recent review by (Fazeli *et al.*, 2016) on waste energy, it was noted that the growing economy of Malaysia contributes to the environmental burden levied by high energy consumption and high volume waste generation. Waste generated in Malaysia is categorised based on the level of potential hazard. According to Department of Environment, waste is defined as " any substance prescribed to be scheduled waste or any matter whether in a solid, semi-solid or liquid form or in the form of a gas or vapour, which is emitted, discharged, or deposited in the environment in such volume, composition, or manner as to cause pollution (DOE, 2001). Scheduled waste is the categories of waste listed in the First Schedule of the Environmental Quality (Scheduled Wastes) Regulations 2005. Sources of scheduled waste generated in Malaysia mainly from cement manufacturing, water treatment plant/power station, coal-fired power plant, chemical manufacturing operations, oleochemical and many more heavy industries (Jamin and Mahmood, 2015).

Waste generation from many sectors contributes to a significant amount of solid waste annually. In Malaysia, solid wastes are generally categorized into three major categories and each category under the responsibility of a different government department. There is a municipal solid waste (MSW) under Ministry of Housing and Local department, schedule/hazardous waste under Department of Environment (DOE) and clinical waste under Ministry of Health (Manaf *et al.*, 2009). At present, landfilling is the only method used for the disposal of MSW, and most of the landfill sites are open dumping areas, which pose serious environmental and social threats (Yunus and Kadir, 2006). With regard to economic aspects, in general, landfilling is the simplest, least expensive, and most cost-effective method of waste disposal (Allen, 2002). Disposal of waste through landfilling is becoming more difficult because existing new landfill sites are filling up at a very fast rate. At the same time, constructing new landfill sites is becoming more difficult because of land scarcity and the increase of land prices and high demands, especially in urban areas due to the increase in population (Manaf *et al.*, 2009). To reduce or to minimise the negative impact caused by these wastes, various ways and methods or process has been implemented including 3R concepts which are Reduce, Reuse and Recycle respectively. For instance, the utilization of solid wastes such as from agro- waste (organic), industrial waste (inorganic), mining waste, non-hazardous waste and hazardous waste to produce construction materials such as wall panels, roof sheets, brick, particle board, fine and coarse aggregate, tiles, and other innovative products (Safiuddin *et al.*, 2010).

The addition of waste or by-product to concrete opens a new pathway in research activities, where concrete as a construction material is integrated with environmental technology. Chemical manufacturing such as plastic and synthetic rubber and polymer dispersion sectors produce a significant amount of polymeric waste materials during the manufacturing process, and these are known to pose problem occupying considerable space on landfills. Several types of research have been conducted with a view to converting waste materials into useful by-product rather than disposing of them in landfills or incinerators. Examples of such materials which have been reported for instance, Topçu, and Uygunoglu (2016) studied on the behaviour of concrete with the incorporation of waste rubber. Sharma, and Bansa (2016) revealed recent studies regarding the utilization of waste plastic in concrete and other related studies using waste material in concrete. Based on the need to promote effective environmental management that supports the drive for sustainable development, there is a strong expectation for the adoption of proper methods of protecting the environment from the cross-section of the industries. The burden of waste management on industries is therefore critical for their successful operations. For this reason, it is economically and environmentally viable to utilise waste or by-product from industries to minimise the problem of waste disposal as well as for sustainability environment.

1.2 Background of the Study

Concrete is known to be the most widely used in the world with global annual production of up to 20 billion metric tonnes (Mehta and Meryman, 2009). Its low cost, ease of application and compressive strength are the main reasons for its universal acceptance (Muthukumar and Mohan, 2004). However, there are many shortcomings of Portland cement concrete or mortar in its fresh as well as hardened states are cause for concern. The common observable inadequacies in its fresh state are bleeding, segregation, excessive air entrainment, high surface tension, rapid loss of workability and rough surface texture. Moreover, while prolonging water or moist curing assist the concrete in tremendous and consistent strength appreciation, this exercise is both labours as well as cost intensive.

The common inadequacies of the hardened normal concrete or mortar are reflected in low tensile strength, flexural strength, modulus of rupture, toughness and energy absorption capacity, and high porosity that consequently affect the durability negatively. Water-based polymer emulsion or latex of copolymer types, when added to concrete or mortar system, improves many of the inadequacies. Due to its mobility, latex can improve the cohesiveness of the concrete matrix, reduces the chances of bleeding. However, it entraps a high percentage of air, which is liable to affect the concrete compressive strength considerably (Ray *et al.*, 1994). Furthermore, according to Ohama (1995) which stated that concrete or mortar has some drawbacks due to delayed hardening, higher drying shrinkage and low chemical resistance. These problems have been solved for some applications to improve the quality of concrete by introducing polymer compounds such as latexes, redispersible polymer powder, water-soluble polymers, liquid resins and monomers as an active ingredient at modifying or improving the performance of concrete. In the search for alternatives ways to improve strength and durability properties as well as to minimise or reduce concrete cost using environmentally friendly concrete, while utilising waste material for sustainable construction. Appreciable reported of studies have utilised various forms of polymeric waste in concrete specimen sourced from different types of solid waste materials most especially in paint industries.

Concrete-polymer composites are made from whole or partial replacement of Portland cement hydrate binder in conventional concrete with organic polymers. The composite system works by strengthening the cement hydrate binder with the polymers. Utilizing the principles of their process techniques, the concrete polymer composites are commonly classified as Polymer-modified mortar (PMM or PCM) and Polymer-modified concrete (PMC or PCC), Polymer mortar (PM) and Polymer concrete (PC) and Polymer-impregnated mortar (PIM) and concrete (PIC) (Fowler, 1999; Ohama, 1997). The monomers also called homopolymer are the basic unit of polymers joining together to form long chain molecules. However, some polymers are formed from copolymers which are two or more monomers joined to form the copolymers. Polymers are also classified as an elastomer, thermosetting or thermoplastic, each characterised by the relative degree of crosslinking of the polymer chains. The physical characteristic of the polymers is influenced by the effectiveness and density of the crosslinking (Kardon, 1997). The polymer content or mass-based polymer – cement (p/c) ratio, exert significant influence on the behaviour of the polymer. The properties of polymer modified concrete depend on the polymer content or mass-based polymer-cement (p/c) ratio, rather than the water-cement ratio (w/c) when assessing ordinary Portland cement concrete. While using polymer-based or polymeric admixtures in cementitious composites such as concrete, the need to ensure that both cement hydration and polymer film formation proceeds are paramount so as to yield a monolithic matrix phase with a network structure in which the cement hydrate phase and polymer phase interpenetrate (Gemert *et al.*, 2005). The superior properties of polymer-based composites in comparison with traditional cementitious materials results from the formation of the monolithic matrix phase. The distinctly enhanced properties of fresh and hardened phases of polymer modified concrete as against the conventional mix designs are attributable to many factors such as polymer type, polymer/cement ratio, water/cement ratio, air content and curing conditions. It is noteworthy that target properties can be achieved through the control of these factors during manufacture process (Almesfer *et al.*, 2012).

Currently, waste latex paint is being disposed of in a landfill without any meaningful reuse. This practice which does not take into account the inherent value attached to its reusability is faced with an attendant considerable economic and environmental cost. The properties of waste latex paint in certain aspects are similar to polymeric admixtures used in concrete production. For instance, the recycling of waste latex paint in concrete such an efforted done by Nehdi and Sumner (2003), using a collection of waste paint as an admixture in concrete. The latexes used as binder paint is a type of polymer dispersion product that suitable to be used in concrete. Hence, the properties of this latex could be similar to the characteristics of pure latexes used in concrete. The solid mass in paints is mainly made up of polymers and tends to behave like polymeric admixtures which have been an active ingredient in the modification of cementitious applications for well over seven decades ago. Polymeric admixtures perform the role of enhancing the bond between the concrete aggregate matrix and the cement. These is due to the polymer when incorporate with concrete mixes, the polymer particles are uniformly dispersed in the cement paste phase. With water withdrawal by cement hydration, the close-packed layer polymer particles coalesce into continuous films, and the films bind the cement hydrates together to form a monolithic network in which the polymer phase interpenetrates throughout the cement hydrate phase (Ohama, 1995). With these characteristics, polymer cement concrete made with polymer latex exhibit excellent bonding to steel reinforcement and to old concrete. This bonding benefitting the modified concrete which provide good ductility, increased the water proofness, resistance to penetration by water and salt, and resistance to freeze-thaw damage (Blaga and Beaudoin, 1985). The addition of polymers makes the concrete mix to become more workable, and improved the workability of concrete. However, the propertis of polymer cement concrete are thus dependent on the type of polymer and/or its amount.

The use of concrete-polymer composites as construction material might drastically increase the cost of a project; therefore it should be used for particular conditions or occasions. For instance, the utilisation of polymer to overcome the crack problem associated to the poor performance of concrete. Epoxy resin is one of common polymer that generally used in crack repair systems . The application of carbon fiber reinforced polymers (CFRP) is used in repair and the rehabilitation of reinforced concrete which offers superior performance in resistance in corrosion and high stiffness to weight ratio (Kasapoglu, 2008). Polymers containing large amounts of filler and mainly used as protective coatings in concrete, reinforced concrete, and rarely on steel which capable of withstanding in severe corrosive environments. In spite of high cost, polymer concrete notably useful for maintenance and repairs, espeacially when it is requires to avoid delay and inconvenience (Halliwell, 2015). Furthermore, the benefits of using concrete-polymer composite including their superior properties in performance of concrete , reduce labour cost and low energy requirements (Figovsky and Beilin, 2014).

1.3 Problem Statement

The universally accepted role of paint and coating materials in the present day has made the products a globally demanded item. Extensive application of paint and coating materials has had impact on the increasing production of these materials. Water-based paint production is steadily growing, owing to its wide acceptance as a coating material for most buildings. Also, the need to control solvents use for paint production through the imposition of environmental regulations especially as it concerns health is responsible for the growth of the water-based paint. Polyvinyl acetate is a primary ingredient in the production of the paints. These polymers compared to others, are used extensively to produce emulsion paints for interior application. These type of coatings are flexible and durable, adhere well, dry quickly and generally do not discolour (Randall, 1992). The increase in demand for the paint has naturally called for a progressive increase in the production to match the increase in demand for the paint. However, significant waste in the form of vinyl acetate effluent is generated during production of the paint thereby raising concern for its disposal especially when an increase in production as a result of demand directly influences the volume of waste generated thereby posing waste disposal problem. For instance, the expected growth rate of Malaysian paint consumption is put at about 3.5% per annum, and the absolute volume of consumption was forecasted to be about 166,000 metrics tones in 2014 (Reg, 2010). However, the percentage increases whereby an overview report is revealed that the Malaysian paint and coating industry recorded total sales amounting RM 3.64 billion at 257,047 metric tonnes in 2016 (CRCG, 2017). The consumption paint has a strong tendency to increase paint waste generation and landfill occupation by these industries. This figure is predisposed to proliferate with advancement in economic activities. Any devised means to recycle this waste would appreciably result to solve the environmental pollution problem and at the same time provide some inherent economic advantage.

The growing interest to recycle waste material from paint production by using it to modify concrete mixes is discernible. While several works have been done in the co-operating the cement with the paint waste to improve the properties of concrete (Nehdi and Sumner, 2003; Mohammed *et al.*, 2008; Ismail *et al.*, 2011;

Ismail and Al-Hashmi, 2011; Almesfer *et al.*, 2012), there are little research findings on the application of polyvinyl acetate waste from paint production in preparation of concrete normal strength. Therefore, this study is aimed to investigate the effect of polyvinyl acetate waste on fresh and hardened states, and durability to improve the properties of concrete. The material is in the liquid form taken from rinse of equipment washing activities in a paint factory. The utilisation of this material may show some excellent properties especially in durability study, that could emanate from it use in the concrete production not only for resource preservation and disposal concerns but also to evaluate the potential of the material can be used in concrete production.

1.4 Aim and Objective of the Study

This study aims to investigate the possibilities of using polyvinyl acetate waste as an ingredient in polymer modified concrete with the following objectives:

1. To characterise properties of polyvinyl acetate waste.
2. To assess the effect of polyvinyl acetate waste on fresh and hardened properties of concrete.
3. To determine the effect of polyvinyl acetate waste on durability performance of polymer modified concrete.

1.5 Research Hypothesis

In this study, it is hypothesised that polyvinyl acetate waste can be incorporated as polymer admixture to enhance the strength and durability properties of concrete significantly.

1.6 Scope and Limitations of the Study

The experimental study focuses on the utilisation and characterisation of polyvinyl acetate waste in concrete. The addition by weight of cement with polyvinyl acetate waste ranged from 0% to 20%. The samples are cured and measured at 7, 28 and 56 days. The study emphasises on the characterisation of polyvinyl acetate waste, properties of concrete at fresh and hardened states, as well as durability of concrete with polyvinyl acetate waste polymer. Furthermore, the morphological studies on microscopic observations of matrix networks, principally between cement and latex particles are also carried out

1.7 Significance of the Research

There is possible potential, innovative and cost benefitting the polymer modified concrete by utilising polyvinyl acetate waste as polymer additive to conventional concrete that will undoubtedly encourage and promote sustainable development, saving preserved natural resources and dumping spaces for maintaining a clean environment:

i. The utilisation of polyvinyl acetate waste in concrete will be an innovative product to enhance strength and durability properties of concrete.

ii. The utilisation of polyvinyl acetate waste will benefit in cost respectively, instead of using other branded chemical resin purely that would give similar behaviour in concrete. One such examples is the evaluation of acoutic absorption behaviour in the concrete. Brancher *et al.* (2016) utilised the polymer ethylene vinyl acetate waste in measuring the effect of acoustic absorption in the floor have similar effect with the study done by Kim *et al.* (2016) which used acrylic polymer emulsion resin in measuring the acoustic performance of the floor system. The performed investigations show that there is possible to use polymeric residues in a new product showing promising acoustic and thermal performance if compared with unmodified concrete.

iii. The utilisation of polyvinyl acetate waste helps to reduce landfill problem associated with this waste by recycling the effluents to produce a meaningful concrete product.

iv. The advantage of having the polyvinyl acetate waste is improving the surface of the concrete in addition to enhancing the aesthetics of the reinforced concrete structure. For instance, when a blemish appears on the concrete structure surface, it shows that it could be one of these concrete defects: blisters, cracking, crazing, curling, delamination, discolouration, dusting, efflorescence, low spots, popouts, scaling or spalling. These deficiencies can be due to various reasons or causes such as structural deficiency resulting from errors in design, loading criteria, unexpected overloading, and construction defects. The concrete defect also caused by damage due to chemical attack, marine environment, exposed to fire, flood, earthquake, cyclone and other relating causes. However, to minimise these defects, polymer latexes are one of the types of admixture used to overcome some of those defects. These are proved by recent studies which utilised the waste latex paint in concrete which minimised the concrete surface defects from other physical and chemical attack by reduction of permeability and porosity in concrete due to polymer latex (Nehdi and Sumner, 2003; Mohammed *et al.*, 2008).

v. Finally, when the technology of polymer modified concrete incorporating polyvinyl acetate waste is adequately established, it will enhance sustainability through reduced environmental impact and reduced cost of the waste disposal, thus producing sustainable concrete.

1.8 Research Approach

i. Carry out a detailed literature review on the utilisation of polymer additive in concrete and other related works on construction.

ii. Select the materials such as cement, polyvinyl acetate waste, aggregate and other materials taking their characteristics into consideration.

iii. Establish test procedures of various standards (ASTM, BS, and RILEM) to be adopted to perform various tests on mortars and concrete specimen prepared from ordinary Portland cement and relating their performance to those prepared from production of concrete containing polyvinyl acetate waste.

iv. Conduct a preliminary study and trial mixes to obtain information that is useful for the refined experimental design employed in the full-scale experiment.

v. Develop a well-planned schedule of experimental tests to study the effect of polyvinyl acetate waste on cementitious composites in relation to specimen prepared from Portland cement alone.

vi. Carry out complementary studies to obtain insights on the effect of polyvinyl acetate waste on strength, deformation and durability properties of concrete.

vii. Conduct microstructural examination on specimen prepared from polymer modified concrete incorporating polyvinyl acetate waste and OPC concrete.

viii. Analyse results of tests conducted and present discussions on the findings on the use of polyvinyl acetate waste in concrete.

ix. Draw conclusions and present recommendations on the application of polyvinyl acetate waste as a new innovative polymer modified concrete for construction.

x. Make suggestions of areas for further research of polymer of modified concrete incorporating polyvinyl acetate waste application in concrete.

1.9 Organization of the Thesis

Chapter One: In this chapter, a general appraisal and a brief description of the background problem is discussed. Furthermore, the chapter indicates the aims and objectives, scope and limitation, research hypothesis, research question, the significance of research and the research approach.

Chapter Two: This chapter provides a logical characterisation of Portland cement and critical discourse of the past research works on the utilisation of polymer thermoplastic materials. A review of the state-of-the-art knowledge on the application of polymer materials in concrete is discussed. However, despite the scanty availability of literature on the incorporation of polyvinyl acetate waste in concrete, a few available additions to many related to the field of polymer in concrete are reviewed.

Chapter Three: The chapter presents materials used for the study and methodology adopted following the appropriate standards and modified published procedures necessary for conducting various tests.

Chapter Four: The results of physical as well as chemical properties of the polyvinyl acetate waste and its effect on fresh concrete properties are presented. Parameters of study in this chapter are workability as it relates to the slump of concrete, air content, setting time of cement and heat of hydration. Presentation of the results obtained and discussion made on the evaluation of mechanical properties is done. Tests falling in this category include compressive, flexural, and tensile strength.

Chapter Five: The chapter contains the evaluation and discussion of deformation behaviour of concrete as influenced by polyvinyl acetate waste on drying shrinkage and reinforced concrete beam. In this chapter, results of Microstructural studies involve field emission scanning electron micrograph (FESEM), energy dispersive X-ray (EDX), thermogravimetric analysis (TGA), and Mercury intrusion porosimetry (MIP) are presented and discussed.

Chapter Six: This chapter consists of the results and discussion arising from various durability tests conducted on OPC concrete and polymer modified concrete incorporating polyvinyl acetate waste. Aspects of durability performance considered in this chapter are water absorption, sorptivity, acid and sulphate attack, fire endurance and leaching.

Chapter seven: This is the concluding chapter of the thesis. In this chapter, the findings and achievements of the study objectives and the contribution of the research to the existing knowledge are stated. Recommendations made for further studies in related areas with a view on improving concrete quality using polyvinyl acetate waste for use as an alternative admixture in concrete are stated.

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