STRENGTH, DURABILITY AND MICROSTRUCTURAL ANALYSIS OF CONCRETE INCORPORATING WASTE CARPET FIBRE AND PALM OIL FUEL ASH

HOSSEIN MOHAMMADHOSSEINI

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Universiti Teknologi Malaysia

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To my lovely parents

Late Haj Mohammadmorad and Hajiyah Nabat

And

My beloved family

Specially my brother Reza, without him none of my successes would be possible

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ABSTRACT

Fibre reinforced concrete (FRC) is a conventional concrete mix that contains cement, coarse and fine aggregates and a dispersion of discontinuous short fibres that are randomly distributed in the fresh concrete mix. The fibres improve the ductility, energy absorption and tensile and flexural strengths of concrete mixture. With the increasing amount of waste generation from various processes, there has been a growing interest in the utilization of waste in producing building materials to achieve potential benefits. In the construction industry, the idea of sustainability encourages the use of waste products to replace raw materials, such as fine and coarse aggregates, cement and fibrous materials. This leads to sustainable, green and environmentally friendly construction by reducing the price of the components compared to disposing of the materials. This research, therefore, focuses on the effects of waste carpet fibre (WCF) and palm oil fuel ash (POFA) as partial replacements of ordinary Portland cement (OPC) on the fresh and hardened properties of concrete. Six volume varying from 0-1.25% of 20-mm-long carpet fibre were used with OPC concrete mixes. Another six mixes were made that replaced OPC with 20% POFA. The water/binder (w/b) ratio of 0.47 was kept constant in all mixes. Fresh properties of concrete were studied with respect to its workability in terms of slump values and Vebe time, unit weight, air content and heat of hydration. The hardened properties examined are; mechanical strengths, deformation characteristics and durability properties. Various techniques, including the use of scanning electronic microscope (SEM), X-ray diffraction (XRD), thermogravimetric analysis (TGA) and differential thermal analysis (DTA) were used to study the microstructure of the concrete. A 3-phased investigation revealed that both carpet fibres and POFA have a potential to be used in the development of concrete properties. The combination of WCF and POFA decreased the slump values and increased the Vebe time of fresh concrete. The unit weight and air content significantly decreased, while the heat of hydration was also reduced. The inclusion of carpet fibre to either OPC or POFA concrete mixes did not improve the compressive strength and modulus of elasticity at early ages. At later ages, however, the compressive strength of the mixtures containing POFA significantly increased and the obtained values were higher than that mixes with OPC alone. The positive interaction between carpet fibres and POFA leads to high tensile strength, flexural strengths and impact resistance, thereby increasing the concrete ductility and toughness with higher energy absorption and improved crack distribution. The creep and drying shrinkage were also considerably reduced. The durability and microstructural characteristics of the respective FRC were significantly improved. The study showed that the use of waste carpet fibre and palm oil fuel ash in the production of sustainable green concrete is feasible both technically and environmentally.

ABSTRAK

Konkrit bertetulang gentian (FRC) merupakan bancuhan konkrit konvensional yang mengandungi simen, batu baur kasar, batu baur halus, dan gentian pendek yang terserak secara rawak di dalam bancuhan konkrit basah. Kehadiran gentian meningkatkan kemuluran, tenaga serapan, kekuatan tegangan dan lenturan bancuhan konkrit. Peningkatan jumlah bahan buangan yang berpunca daripada pelbagai proses menjadikannya semakin mendapat perhatian untuk menghasilkan bahan-bahan binaan bagi mencapai potensi kebaikan penggunaan sisa buangan tersebut. Dalam industri pembinaan, idea kelestarian menjadi pemangkin kepada penggunaan sisa bahan buangan sebagai pengganti bahan mentah seperti batu baur halus dan kasar, simen, serta gentian. Hal ini membantu ke arah pembinaan yang lestari, hijau dan mesra alam sekitar dengan pengurangan kos komponen bahan berbanding pelupusan bahan tersebut. Oleh itu, kajian ini tertumpu kepada kesan sisa gentian hamparan (WCF) dan abu terbang kelapa sawit (POFA) sebagai penggantian sebahagian simen Portland biasa (OPC) terhadap konkrit basah dan keras. Enam pecahan isi padu bermula dengan 0-1,25% daripada 20 mm panjang gentian hamparan digunakan dengan bancuhan konkrit OPC. Enam campuran lain pula dibuat menggantikan OPC dengan 20% kandungan POFA. Nisbah air kepada bahan pengikat (w/b) yang dikekalkan secara malar dalam semua bancuhan ialah 0.47. Sifat konkrit basah yang dikaji berkaitan dengan kebolehkerjaan konkrit tersebut ialah melalui nilai ujian runtuhan, ujian masa Vebe, berat unit, kandungan udara dan haba penghidratan. Sifat konkrit keras yang dikaji termasuk kekuatan mekanikal, ciri-ciri ubah bentuk dan sifat ketahanan konkrit keras tersebut. Pelbagai teknik digunakan untuk mengkaji mikrostruktur konkrit termasuk imbasan mikroskop elektronik (SEM), belauan sinar-X (XRD), analisa termogravimetri (TGA) dan analisa terma bezaan (DTA). Kaji selidik 3-fasa menunjukkan bahawa kedua-dua WCF dan POFA berpotensi digunakan dalam penghasilan sifat-sifat konkrit. Campuran WCF dan POFA mengurangkan nilai runtuhan dan meningkatkan masa Vebe konkrit basah. Berat unit dan kandungan udara berkurang dengan ketara manakala haba penghidratan juga dikurangkan. Rangkuman gentian hamparan sama ada terhadap bancuhan konkrit OPC ataupun POFA tidak meningkatkan kekuatan mampatan dan modulus keanjalan pada usia awal.Walau bagaimanapun, ketika konkrit mencapai umur selanjutnya, kekuatan mampatan bancuhan konkrit yang mengandungi POFA meningkat dan nilai yang diperoleh adalah lebih tinggi daripada nilai bancuhan simen OPC semata-mata. Interaksi positif antara gentian hamparan dengan POFA menghasilkan peningkatan kepada kekuatan tegangan yang tinggi, kekuatan lenturan dan rintangan hentaman, sekaligus meningkatkan kemuluran dan ketahanan konkrit serta meningkatkan tenaga serapan dan memperbaiki serakan retak.Nilai rayapan dan pengecutan konkrit yang dikaji turut menurun. Ketahanan dan ciri-ciri mikrostruktur FRC turut mengalami penambahbaikan yang ketara.Kajian ini membuktikan penggunaan sisa gentian hamparan dan abu terbang kelapa sawit dalam pengeluaran konkrit lestari dan hijau boleh dilaksanakan dari segi teknikal dan alam sekitar.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Standards for Testing of Materials
BS EN	-	British Standard
CRT	-	Constant-Rate of Traverse
CS	-	Compressive Strength
DTA	-	Differential Thermal Analysis
FA	-	Fly Ash
FRC	-	Fibre Reinforced Concrete
GGBS	-	Ground Granulated Blast Furnace Slag
GFRC	-	Glass Fibre Reinforced Concrete
IS	-	Indian Standard
LOI	-	Loss on Ignition
LVDT	-	Linear Voltage Displacement Transducer
MOE	-	Modulus of Elasticity
OPC	-	Ordinary Portland Cement
PAN	-	Polyacrylonitrile
PC	-	Plain Concrete
PFCS	-	Post Failure Compressive Strength
POFA	-	Palm Oil Fuel Ash
PP	-	Polypropylene
PPM	-	Parts Per Million
RC	-	Reinforced Concrete
RHA	-	Rice Husk Ash
RILEM	-	International Union of Laboratories and Experts in Construction Materials, Systems, and Structures
SCM	-	Supplementary Cementing Materials
SEM	-	Scanning Electron Microscopy

SF	-	Silica Fume
SP	-	Superplasticiser
SSD	-	Saturated Surface Dry
TGA	-	Thermogravimetry Analysis
UPV	-	Ultrasonic Pulse Velocity
w/b	-	Water/Binder
w/c	-	Water/Cement
WCF	-	Waste Carpet Fibre
XRD	-	X-ray Diffraction

LIST OF SYMBOLS

$3CaO.Al_2O_3.$ $3CaSO_4.32H_2O$	-	Ettringite
a	-	The exposed area of the specimen, in mm^2
A_1	-	Apparent air content of the sample (%)
A_c	-	The cross sectional area of the specimen (mm^2)
$AgNO_3$	-	Silver nitrate
Al	-	Alumina
Al_2O_3	-	Aluminium oxide
B	-	Binder
C	-	Carbon
C_2S	-	Dicalcium silicate
C_3Al	-	Tricalcium aluminate
C_3S	-	Tricalcium silicate
Ca	-	Calcium
$Ca(OH)_2$	-	Calcium hydroxide
CaO	-	Calcium oxide
C-A-S-H	-	Calcium alumina silicate hydrate
$CaSO_4.2HO_2$	-	Gypsum
Cl	-	Chloride
CO_2	-	Carbon dioxide
C-S-H	-	Calcium silicate hydrate
ρ	-	Measured density (kg/m^3)
d_1 , d_2	-	Lateral dimension of the specimen (mm)
d_f	-	Diameter of fibre
$\mathcal{E}(t_o)$	-	Average total measured strain at any time t_o
$\mathcal{E}_c(t)$	-	Creep strain at any time t_o

$\mathcal{E}_e$	-	Average instantaneous elastic strain recorded after loading
$\mathcal{E}_{sh}(t_o)$	-	Average strain at any time t_o (determined on unloaded specimen)
F	-	The maximum load at failure (N)
f_c	-	Compressive Strength (MPa)
F_{ca}	-	The average compressive strength of the specimen after immersion in sulphate or acid solutions (MPa)
f_{cf}	-	Flexural strength (MPa)
f_{ct}	-	Splitting tensile strength (MPa)
F_{cw}	-	The average compressive strength of companion specimen cured in water (MPa)
Fe	-	Iron
Fe_2O_3	-	Iron oxide
g	-	Acceleration due to gravity
H_1	-	Water level reading at the required pressure (1.4 kPa)
H_2	-	Water level reading at zero pressure after release of pressure
H_2O	-	Water
H_2SO_4	-	Sulphuric acid
l	-	Distance between the lower roller (mm)
I	-	The absorption
K	-	Potassium
K_2O	-	Alkalis
L	-	Length of the specimen (mm)
l_c	-	Critical length of fibre (mm)
l_f	-	Length of fibre (mm)
m	-	The mass of the hammer (kg)
M	-	Coefficient of comparator meter
M_c	-	Mass of the measure filled with concrete (kg)
M_d	-	Oven-dry mass of the specimen in air (kg)
Mg	-	Magnesium
MgO	-	Magnesium oxide

$MgSO_4$	-	Magnesium sulphate
M_m	-	Mass of the measure (kg)
M_s	-	Saturated surface dry mass of the specimen in air (kg)
m_t	-	The change in specimen mass in grams, at the time t
NaCl	-	Sodium chloride
SiO_2	-	Silicon dioxide
SLF	-	Strength loss factor (%)
SO_3	-	Sulphur trioxide
t	-	The time that hammer need drop (0.3053 Sec)
U	-	The impact energy of the hammer for each blow in kN mm
V	-	The velocity of the hammer
V_{cr}	-	Critical fibre volume fraction
V_m	-	Volume of the measure (m^3)
W	-	The weight of the hammer
W_a	-	Water absorption (mass %)
τ	-	Shear strength of matrix
σ^*_f	-	Ultimate tensile strength of fibre
σ_{mu}	-	Ultimate strength of concrete matrix
σ'_{fu}	-	Stress on the fibre at first crack
σ_{fu}	-	Ultimate strength of fibre

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CHAPTER 1

INTRODUCTION

1.1 General

Through industrialization and technological developments in various fields, huge amount and different sorts of solid waste materials have been generated by the industrial, mining, agricultural and domestic actions. Therefore, solid waste management has become one of the main ecological concerns in all around the world. With the increasing attentiveness about the environment, lack of landfill area and because of its high cost, utilization of by-products and waste materials has become an attractive alternative to disposal. Recycling of the non-biodegradable wastes is very difficult. Utilization of natural sources, large quantity production of industrial waste and environmental contamination need gaining new and applicable solutions for a sustainable development. Over the decades there has been a rising affirmation on the use of by-products and waste materials in construction industry. In the construction, the idea of sustainability allowed the use of waste products to replace raw materials, such as fine and coarse aggregates, cement and fibrous materials. Use of these waste materials not only aids in getting them applied in concrete, and other construction materials, it helps in decreasing the cost of the concrete producing, but also has many indirect advantages such as decrease in landfill area, saving in energy, and defending the environment from possible pollution effects. Further, utilization of these waste materials may develop the physical and mechanical, durability and microstructural properties of concrete, which are challenging to achieve by the use of only raw materials (Putman & Amirkhanian 2004; Batayneh *et al*. 2007; Meddah & Bencheikh 2009; Kanadasan & Abdul Razak 2015; Gu & Ozbakkaloglu 2016).

A main challenge facing the construction industries is to execute projects in compatibility with the environment by adopting the concept of sustainable development. This involves the use of high performance and eco-friendly materials produced at a reasonable quality and cost. Current researches on many waste materials such as supplementary cementing materials (SCMs), plastics and textiles, aggregates and a host of others have shown that the addition of such waste materials in concrete has the potential to enhance the physical, mechanical and durability of concrete as well as a reduction in the cost of construction (Chandra 1997; Siddique *et al*. 2008; Thomas & Gupta 2013). The challenges are more a consequence of the facts that Portland cement is not particularly eco-friendly and lack of landfill space for waste materials. One could then decrease these challenges to the succeeding simple formula: use as much concrete, but with as low Portland cement as possible, and waste materials as much as possible, this means to substitute as much raw material as possible by waste and SCMs, particularly those that are by-products of industrial processes, and to use waste materials instead of natural resources.

Synthetic fibres are industrialized mainly to supply the high demand for textile and carpet products. Polypropylene and nylon are the most synthetic fibres used in these industries. In waste streams, carpets are classified as textiles, and generated either from post-consumer or pre-consumer (industries). The approximate amount of the industrial waste carpet fibres generated in Malaysia is estimated as 30 to 50 tons annually, reported by Malaysian carpet industries. The benefits of using such recycled fibres include generally lower cost to process than virgin fibres, light in weight, good acid and alkali resistance and non-absorbent of water (Wang *et al*. 1994; Wang *et al*. 2000; Schmidt & Cies 2008; Ghosni *et al*. 2013). The pozzolanic materials are used all over the world for their technical, economic and ecological benefits. One of the latest inclusion in the ash family is palm oil fuel ash (POFA), obtained on burning palm oil husk and palm kernel shell as fuel in palm oil mills (Tay 1990; Awal & Hussin 1997; Tangchirapat *et al*. 2007). Malaysia is the second largest producer of oil palm and palm oil products in the world. In 2007, about 3 million tons of POFA have been produced in Malaysia, and this production rate is likely to rise due to increase the plantation of palm oil trees (Ismail *et al*. 2011; Al-Mulali *et al*. 2015; Ranjbar *et al*. 2016).

Weighing up the cleaner production, waste materials from various sources need to be propounded as potentially valuable materials. Among them are the industrial waste carpet fibre and POFA, the disposal and landfilling of which have detrimental effects on the environment due to their long disintegration period. One of the reasonable approaches to minimize the adverse effects is the utilization of waste materials as useful resources in other industries, like green building construction. To date, only a few studies have been carried out on the development of concrete composites from carpet waste (Vilkner *et al*. 2004; Zhou & Xiang 2011). Such developments would create a stable pathway for carpet waste and provide new materials for structural applications. However, research work on the utilization of carpet waste and POFA, as partial replacement of cement in concrete, has not been investigated earlier.

1.2 Background of the Problem

Concrete is the most important construction material and its consumption is increasing all around the globe. In addition to the normal applications, higher ductility and energy absorption capacity are often required in different fields like industrial building floors, highway paving, bridge decks, etc. Nevertheless, conventional concrete possesses very slight tensile strength, limited ductility, low resistance to cracking, and little energy absorption. Internal micro-cracks are inherently exist in the concrete specimens and its low tensile strength is owing to the propagation of such micro-cracks, ultimately leading to brittle fracture of the concrete. Therefore, enhancing the toughness of concrete and decreasing the size and possibility of weaknesses would lead to better concrete performance.

Previously, efforts have been made to impart enhancement in tensile properties of concrete by way of adding a small fraction (0.5-2%) of short fibres to the concrete mixture throughout mixing process (Zollo 1997; Brandt 2008; Yahaghi *et al*. 2016). In such situations fibre reinforced concrete (FRC) has been shown to perform its functions satisfactorily. Fibre reinforced concrete can be defined as a composite material containing of mixtures of cement, coarse and fine aggregates, and a dispersion of discontinuous short fibres that are randomly distributed in the fresh concrete mix. There are various types of fibres, no matter polymeric or metallic, generally utilized in concrete mixture for their benefits. Among others, the most common types fibre used in fibre reinforced concrete are glass fibres, steel fibres, synthetic fibres such as nylon and polypropylene (PP), natural fibres and fibres from pre- and post-consumer wastes. Fibres in general and polypropylene fibres, in particular, have gained popularity recently for use to improve the properties of concrete (Brandt 2008).

In brittle materials like plain concrete without any fibre, micro-cracks develop even before applying load, mainly due to drying shrinkage or any other cause of volume change. While loading, the cracks propagate and open up, and owing to the effect of stress concentration and formation of additional cracks in places of minor defects. The development of such micro-cracks along the concrete members, is the main reason of inelastic deformation in concrete (Hsie *et al.* 2008). It has been recognized that the addition of polypropylene fibre in concrete mixture is potential in bridging the cracks, load transfer, and improving micro-cracks dispersal system (Aldahdooh *et al*. 2014). Moreover, the fibres would act as crack arrester and would significantly enhance the properties of concrete not only under compression, tensile, and flexure (Yap *et al*. 2013), but also under impact blows (Nili & Afroughsabet 2010) and plastic shrinkage cracking (Zhang *et al*. 2011).

One of the fundamental solutions towards attaining enhanced concrete properties in terms of strength, durability and microstructures is the combined use of polypropylene fibre and pozzolanic materials in concrete. Polypropylene fibre is presented in the mixture to reduce brittleness of the matrix thus reducing the susceptibility to cracking of a concrete (Karahan & Atis 2011). As most of the problems related to the durability properties such as permeability, chloride penetration, carbonation, and acid and sulphate attacks start from concrete cracking, a substantial solution that decreases the brittleness of concrete is required and foremost efficient. Fibre reinforced cementitious composites, addresses the brittleness of concrete. This ductile material containing pozzolanic materials, exhibits an excellent ductility under mechanical loading as well as durability under sever environmental exposure (Mo *et al*. 2015). There are many ways to improve the durability of concrete structures. Among all, providing a dense microstructure of concrete specimens through wellgraded particle size distribution to decrease passage of corrosive into the concrete, increase the compressive strength and improve the durability properties of concrete by the addition of admixtures are the most applicable. However, these approaches do not enhance the brittleness behaviour of concrete (Yap *et al*. 2014; Mo *et al*. 2014).

Other than mechanical properties, aspects of durability and microstructural analysis are greatly considered in assessing the behaviour and potential use of any new waste material in concrete. Therefore, a great deal of research is necessary to study in-depth the utilization of these materials on a large scale to develop adequate performance data that will permit changes to construction specifications.

1.3 Statement of the Problem

There is no doubt that cleaner and more efficient management of various forms of waste generation is receiving more attention in order to maintain sustainability in green construction. The utilization of waste materials is one of the fundamental issues of waste management strategies in many parts of the world. The advantages of recycling include reducing environmental pollution, reducing landfilling and disposal of wastes and preserving natural resources. Concrete is typically characterized as brittle materials, with a low tensile strength and energy absorption capacity. Consequently, using fibre reinforced concrete in fields where ductility and durability are the main considerations is an alternative solution. Therefore, consumption of cheaper and viable materials in concrete instead of raw materials is necessary. Since a low volume fraction of short fibres has been suggested for the development of the strength and durability properties of concrete, it paves the way to use waste carpet fibres to get more details on properties of concrete containing this fibre.

During the past decades, many research works on the utilization of waste ashes as supplementary cementing materials in concrete have been carried out. One of the latest inclusion in the ash family is palm oil fuel ash which played an enormous role in this regards. The influence of carpet fibres and POFA on the physical, mechanical, durability and microstructure properties of concrete is not common in the existing studies of literature. Taking into account the availability and the possible fibrous behaviour of waste polypropylene carpet fibres and pozzolanic nature of the POFA, research works on the utilization of the materials have been initiated to investigate the followings;

- The influence of carpet fibre and POFA on the fresh state properties of concrete.
- The combined effect of carpet fibre and POFA on the mechanical, durability and microstructure properties of concrete.

1.4 Aim and Objectives of Study

The aim of the study is to develop the fibre reinforced concrete (FRC) incorporating industrial waste carpet fibre and palm oil fuel ash (POFA). In view of the benefits obtained by the utilization of carpet fibre and POFA, the specific objectives are as follows:

i. To investigate the physical and chemical characteristics of waste carpet fibres and POFA and optimization of fibre' length and POFA content.

ii. To propose a mix design guidelines for the proportioning of waste carpet fibre and POFA for the FRC.

iii. To determine the fresh state, strength and deformation characteristics of fibre reinforced concrete incorporating waste carpet fibres and POFA.

iv. To analyse the durability properties of fibre reinforced concrete incorporating waste carpet fibres and POFA.

v. To evaluate the microstructural characterization and the factors influencing the performance of waste carpet fibre and POFA in FRC.

1.5 Scope of the Study

The research would be experimental in nature and focuses primarily on the development of a fibre reinforced concrete incorporating waste carpet fibres at volume fractions of 0%, 0.25%, 0.5%, 0.75%, 1.0% and 1.25%, and POFA at replacement levels of 10-30% of ordinary Portland cement (OPC). Carpet fibre was used as an addition while POFA was used as supplementary cementing material. Therefore, an essential number of intensive investigations and analysis were performed as mentioned below. The study emphasize physical and mechanical, durability and microstructure properties of concrete, which is believed to be within the limits set by the objectives.

The first phase deals with characterisation of constituent materials and testing of the properties of carpet fibre and POFA. These comprise; density, melting point, tensile strength, water absorption and scanning electron microscopy (SEM) of the carpet fibres. It also deals with the determination of the physical properties and chemical compositions of OPC and POFA by X-ray fluorecence (XRF) and also determination of the morphological and microscopic structure of POFA by SEM and energy dispersive X-ray diffraction (XRD).

The second phase deals with mix design and proportioning of the constituent materials for concrete, and also optimisation process. These contain optimum length of the fibre, optimum POFA content.

The third phase deals with the investigation of fresh and hardened states, durability and microstructure properties of concrete containing carpet fibre and POFA. These contain the slump, VeBe time, fresh density, air content and heat of hydration from fresh concrete and, compressive, splitting tensile and flexural strengths, ultrasonic pulse velocity (UPV), modulus of elasticity, impact resistance, creep and drying shrinkage, water absorption, sorptivity, chloride resistance, sulphate resistance, acid resistance, carbonation depth and fire resistance from hardened concrete. The fourth phase deals with the investegation of microstructural properties such as scanning electron microscopy (SEM), thermogravimetric analysis (TGA), differential thermal analysis (DTA) and X-ray diffractometry (XRD).

1.6 Significance of Study

Large amounts of waste materials cannot be eliminated. Nevertheless, the environmental defects can be reduced by providing more sustainable usage of these waste materials. This is known as the ’’Waste Hierarchy’’. Its goal is to decrease, recycle, or reuse waste, the latter being the desired option of waste disposal. Figure 1.1 displays a drawing of the waste hierarchy. This study is limited to industrial waste carpet fibre and palm oil fuel ash.

Since discontinues short fibres has been proposed for the development of the concrete performance, the use of carpet fibres will result in a reduction of the amount of waste generated from industry and also enhanced the brittleness properties of concrete. Suitably used, POFA can significantly develop the mechanical, deformation and durability properties of concrete which will be decrease the pressure on the industrial and domestic consumption of Portland cement. As both carpet fibre and POFA are industrial waste materials requiring minimal spending, their use will considerably decrease the overall cost of construction, thereby justifying the name of “Green Concrete Composite”. Consequently, the mixture of carpet fibre and POFA to production of concrete composite will open up new research opportunities.

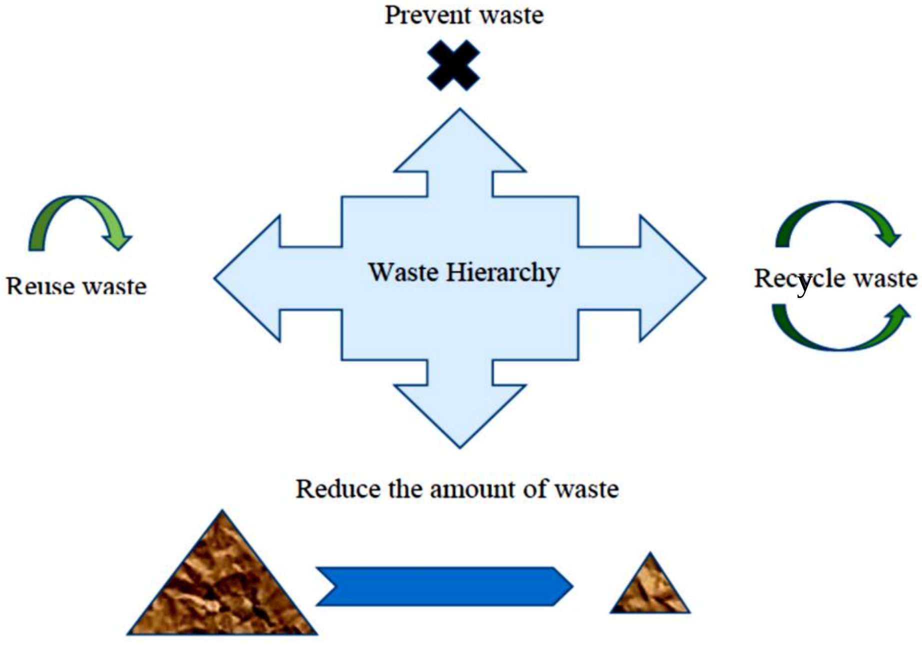

Figure 1.1 The waste hierarchy

1.7 Research Approach

1. Perform a comprehensive literature review on the utilization of waste materials such as waste textile, fibres and pozzolanic ashes in concrete and other related construction activities.

2. Select the waste carpet fibres, POFA, cement, aggregates and other required materials based on their characteristics.

3. Study of various test procedure standards such as BS EN, ASTM, ACI and RILEM for performing tests on concrete containing waste carpet fibres and POFA.

4. Conducting a primary study and trial mixes to verify and control the proposed mix ratios before beginning the full scale experiment.

5. Carry out a series of tests for optimization of fibre’s length and POFA content to use in full scale experiment.

6. Develop an appropriate schedule of experimental programs with test to investigate the combined effect of waste carpet fibre and POFA on concrete composites and compare its performance with that of without any POFA and fibres.

7. Conduct corresponding studies to comprehend the combined effect of carpet fibre and POFA on physical, mechanical, deformation and durability properties of concrete.

8. Inspect and compare microstructure analysis of concrete containing carpet fibre and POFA with that of without any fibres and POFA.

9. Analysis of experimental results and discussions on the findings.

10. Draw conclusions and make available recommendations on the application of waste carpet fibre and palm oil fuel ash as a new fibrous and supplementary cementing materials for construction.

11. Propose fields of further study of waste carpet fibre and POFA applications in concrete industry along with mix design guidelines.

1.8 Thesis Organization

Chapter 1: Provides a general appraisal and an overview of the problem background to support the problem statements. In addition, the chapter also highlights the aim and objectives, scope and limitation of the research. The significance of study and the research approach were clearly spelt out.

Chapter 2: Deals with the critical review of the related and relevant literatures.

Chapter 3: This chapter describes a comprehensive breakdown of the consecutive sequence of the methodology that is occupied for successful achievement of the research from the design stage of the experimental work to its rational conclusions.

Chapter 4: This chapter emphases on the characterization of the constituent materials, comprising the physical properties and chemical compositions of OPC and POFA, and characteristics of waste carpet fibre. The chapter also deals with the mix design of the concrete containing carpet fibre and POFA, and the optimization of the fibre's length and POFA content in terms of workability and strength properties.

Chapter 5: This chapter reveals the physical and mechanical properties of concrete containing carpet fibres and POFA. These include workability in terms of slump and Vebe, fresh density, air content, setting time and heat of hydration for the fresh concrete. It also presents the results obtained and discussion made on the evaluation of mechanical and deformation properties of hardened concrete. Tests falling in this category comprise, compressive strength, post failure compressive strength, tensile and flexural strengths, ultrasonic pulse velocity, modulus of elasticity, impact resistance, drying shrinkage and creep. Moreover, the related microstructure analysis of concrete specimens cured in water for different curing period are also present in this chapter.

Chapter 6: This chapter deals with the results and discussion arising from durability tests conducted on concrete containing carpet fibre and palm oil fuel ash. Durability aspects performed in this chapter are; permeability (water absorption and sorptivity), chloride penetration, sulphate attack, acid attack, carbonation and fire endurance. The durability properties of concrete mixture are also support with microstructure analysis in terms of scanning electron micrograph (SEM), Thermogravimetry analysis (TGA) and X-ray diffraction (XRD), in order to deep understanding the performance of concrete in different environmental conditions.

Chapter 7: The chapter concludes this dissertation by stating the achievements and findings of the study and the contribution of the research to the existing knowledge. Recommendations are also made for further study in related fields to enhance the quality of concrete using waste materials such as carpet fibre and palm oil fuel ash.

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