ENGINEERING PROPERTIES AND DURABILITY OF CONCRETE WITH ARABIC GUM BIOPOLYMER

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task could be accomplished if it is done one step at a time.

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ABSTRACT

The use of materials of vegetal origin is increasingly being promoted in many industries due to their cost-effectiveness and the sensitivity to sustainability and environmental protection. Natural gum is a wild plant by-product that is mainly found in Sudan and is also growing in other African countries. It has long been used in different industries. However, its utilization is very limited in the building sector, although there appears to be a positive potential for the use of Arabic Gum Biopolymer (AGB) in the construction industry. Since most natural gum is produced in Sudan, this study focuses on a Sudanese product called AGB, which has improved the properties of the concrete. The main aim of this research is to evaluate the effect of Arabic Gum Biopolymer on the fresh, physical, mechanical and durability properties of ordinary concrete at different ages and to determine the optimum percentage of AGB that will improve the concrete properties. For this purpose, concrete specimens were designed to evaluate the effect of AGB as an additive to ordinary concrete. AGB was mixed with the water in proportions within the range from 0 to 1.2% of the weight of the water. Fresh concrete properties, physical and mechanical properties were examined in addition to durability properties and microstructural analysis of the concrete. The experimental results showed that initial setting time and workability of the AGB cement mixes increase with AGB content up to an optimal amount fraction of 0.9%. The density, air content and permeability properties gradually were reduced with increase in AGB fraction. The AGB concrete strength was found to exhibit a maximum improvement reaching about 8% for an AGB fraction between 0.7 and 0.9%. The carbonation depth, acid resistance, chloride penetration depth and fire resistance decrease by 11%, 10%, 20 % and 12% respectively, for AGB percentage of 0.9%. X-ray fluorescence (XRF) and X-ray photoelectron spectroscopy (XPS) shows the presence of AGB chemical components in the AGB-added cement. X-ray diffraction (XRD) and Fourier Transformed Infrared Spectrometer (FTIR) analysis results reveal virtually similar hydration pattern of AGB concrete relative to the ordinary Portland cement (OPC) concrete. The scanning electron microscopy (SEM) and Brunauer-Emmett-Teller (BET) surface area analysis, for AGB concrete specimen present fewer voids dispersed in the microstructure of the AGB mixes. This explains the improvement observed in the durability and microstructural properties of the ordinary concrete mixes as a result of AGB addition. The improvement in setting time and workability indicate that AGB can be useful as a retarder and water-reducing admixture, respectively. This suggests that AGB can be integrated into the construction sector, resulting in reducing the chemical admixture demand. Creating new outlets for the AGB material would provide social and economic impacts to construction industry.

ABSTRAK

Penggunaan bahan yang berasal dari tumbuh-tumbuhan semakin dipromosikan dalam banyak industri kerana keberkesanan kos dan peningkatan kepekaan terhadap kelestarian dan perlindungan alam sekitar. Gam semula jadi adalah produk sampingan tumbuhan liar yang banyak terdapat di Sudan dan juga tumbuh di negara-negara Afrika yang lain. Iatelah lama digunakan dalam industri yang berbeza. Namun, penggunaannya sangat terhad di sektor bangunan, walaupun tampaknya ada potensi positif untuk penggunaan Arabic Gum Biopolymer (AGB) dalam industri pembinaan. Oleh kerana kebanyakan gum semulajadi dihasilkan di Sudan, kajian ini memfokuskan pada produk Sudan yang disebut AGB, yang telah meningkatkan sifat konkrit. Tujuan utama penyelidikan ini adalah untuk menilai kesan Biopolimer Gum Arab terhadap sifat segar, fizikal, mekanikal dan ketahanan konkrit biasa pada usia yang berbeza dan untuk menentukan peratusan optimum AGB yang akan meningkatkan konkrit sifat. Untuk tujuan ini, spesimen konkrit direkabentuk untuk menilai kesan AGB sebagai bahan tambah kepada konkrit biasa. AGB dicampurkan dengan air dalam kadar antara 0 hingga 1.2% daripada berat air. Sifat konkrit segar, sifat fizikal dan mekanikal diperiksa di samping sifat ketahanan dan analisis mikro struktur konkrit. Hasil eksperimen menunjukkan bahawa masa penetapan awal dan kebolehkerjaan campuran simen AGB meningkat dengan kandungan AGB hingga pecahan jumlah optimum 0.9%. Ketumpatan, kandungan Udara dan sifat kebolehtelapan berkurang secara dengan peningkatan pecahan AGB. Kekuatan konkrit AGB didapati menunjukkan peningkatan maksimum mencapai sekitar 8% untuk pecahan AGB antara 0.7 dan 0.9%. Kedalaman karbonasi, ketahanan asid dan kedalaman penembusan klorida masing-masing menurun sebanyak 11%, 10% dan 20%, untuk peratusan 0.9%. Pendarfluor sinar-X (XRF) dan X-ray photoelectron spectroscopy (XPS) menunjukkan adanya komponen kimia AGB dalam simen tambahan AGB. Hasil analisis difraksi sinar-X (XRD) dan *Fourier Transformed Infrared Spectrometer* (FTIR) menunjukkan corak penghidratan konkrit AGB yang hampir sama dengan ordinary Portland simen (OPC) konkrit. Mikroskopi elektron imbasan (SEM) dan analisis luas permukaan *Brunauer-Emmett-Teller* (BET), untuk spesimen konkrit AGB menunjukkan lebih sedikit lompang yang tersebar di struktur mikro campuran AGB. Ini menjelaskan peningkatan dalam ketahanan dan sifat mikro struktur campuran konkrit biasa sebagai hasil penambahan AGB. Peningkatan dalam masa pemejalan dan kebolehkerjaan menunjukkan bahawa AGB masing-masing dapat digunakan sebagai bahan tambah pelambat dan pemudan adan. Ini menunjukkan bahawa AGB dapat diintegrasikan ke dalam sektor bangunan, sehingga dapat mengurangkan permintaan bahan tambah kimia. Membuat saluran baru untuk bahan AGB akan memberikan kesan sosial dan ekonomi kepada industri pembinaan.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
AGB	-	Arabic Gum Biopolymer
ASTM	-	American Society for Testing and Materials
ASR	-	Alkali-silica reaction
CSH	-	Calcium silicate hydration
GGBFS	-	Ground Granulated Blast Furnace Slag
NSC	-	Normal Strength concrete
HSC	-	High strength concrete
HPC	-	High performance concrete
IS	-	Indian Standard
MOE	-	Modulus of Elasticity
OPC	-	Ordinary Portland Cement
PC	-	Plain Concrete
RC	-	Reinforced Concrete
RHA	-	Rice Husk Ash
RILEM	-	International Union of Testing and Research Laboratory
SEM	-	Scanning Electronic Microscopy
SF	-	Silica Fume
SP	-	Normal Superplasticiser
SSD	-	Saturated Surface Dry
TGA	-	Thermogravimetry Analysis
UPV	-	Ultrasonic Pulse Velocity
UTM	-	University Teknologi Malaysia
W/C	-	Water to Cement ratio
XRF	-	X-ray Fluorescence
XRD	-	X-ray Diffraction
XPS	-	X-ray Photoelectron Spectroscopy

CHEMICAL FORMULAS

Alumina	-	Al_2O_3
Alumina tri-hydrate	-	$Al(OH)_3$
Boehmite	-	$Al(OH)$
Brucite	-	$Mg_3(OH)_6$
Calcium hydroxide	-	$Ca(OH)_2$
Calcium sulphate	-	$CaSO_4$
Calcium silica hydrate	-	C-S-H
Diaspore	-	$AlO(OH)$
Di-calcium silicate	-	S_2S
Lime	-	CaO
Magnesium oxide	-	MgO
Magnesium sulphate	-	$MgSO_4$
Magnesium oxide	-	MnO
Potassium oxide	-	K_2O
Silica	-	SiO_2
Sodium aluminate	-	$NaAl(OH)_4$
Sodium hydroxide	-	$NaOH$
Sodium oxide	-	Na_2O
Sodium sulphate	-	Na_2SO_4
Titanium oxide	-	TiO_2
Tri-calcium silicate	-	C_3S

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Concrete is an important material in building construction. Every year more than 10,000 million tons are produced worldwide (Meyer, 2009). Concrete is mouldable, adaptable and affordable. It possesses numerous attractive physical and mechanical properties. Moreover, remarkable progress has been made in improving its durability. These properties, together with moderate cost. Explain the popularity of concrete and its abundant use in the construction industry.

Executing construction projects while adhering the concept of environmental compatibility and sustainable development is a challenge facing the construction industry. These concepts call for the use of composite, eco-friendly and natural materials that, when mixed with concrete, can provide it with high strength and performance and can be produced with good quality and at a reasonable cost.

Many researchers have been interested in mixing concrete with other materials, for instance, plastics, textiles, cementation materials, chemicals and mineral admixtures. It has been demonstrated that the addition of such materials in the ordinary concrete has the advantage of improving the physical and hardened properties, durability and microstructure of ordinary concrete (Siddique et al., 2008 ; Hebhoub, 2011; Thomas and Gupta, 2013). However, these additives are generally either synthetic, unsustainable or non-eco-friendly. Thereby, it is opportune to promote affordable natural and sustainable alternative materials for use as concrete admixtures.

Vegetal materials are, progressively, being integrated into the composition of industrial materials given their cost-effectiveness and the growing concern about issues such as sustainability and environmental protection. Natural Arabic Gum

Biopolymer, a wild plant product material found mainly in Sudan (70-85% of world production) (Karamalla, 1998; Mohamed et al., 2016), and also produced in other African areas, has been widely used in many different fields, such as lithography, cosmetics, textiles, encapsulation, pharmaceuticals, the food industry. However, its utilization in the building and construction industry has been very limited.

In one of the earliest research study on the subject, Gum Arabic, a natural gum, has been used as a natural additive in a binder to the glazes of the ceramic in order to increase the glaze mixture workability and fluidity and to increase the clay adhere to the glaze before it is fired, thus decreasing the handling damage during the manufacturing process.

In a later study, the influence of adding water dissolved Gum Arabic, to the concrete mixture on the properties of concrete was evaluated. The study concluded that Gum Arabic provide better workability and higher compressive strength (Abdeljaleel et al., 2012). This provided evidence that AGB has the potential for being a useful additive that would improve some fresh and hardened properties of the ordinary concrete.

In the last few decades, considerable improvement in concrete performance has been achieved, essentially, through the development of effective industrial admixtures, such as fly ash (Naik et al., 2001). High performance concretes, self-compacting concrete and eco-concrete (Zakka et al., 2015) are a few examples that illustrate the important role of admixtures.

Prior investigations have dealt with natural gums form different origins, and it is known that the chemical elements and the properties of this natural product depend on the geographic origin, harvest season, climate and age of the tree. Since most natural gum is produced in Sudan, the focus of this study will be on a Sudanese product called Arabic Gum Biopolymer (AGB).

Concrete is the commonly used material in the construction worldwide. In addition to the physical and mechanical properties, energy demand and durability are

primary considerations in several construction sectors, such as highways and pavement, bridge peers and slaps, industrial buildings etc. Moreover, the performance of ordinary concrete is not ideal in terms of properties such as initial and final setting times, compressive strength, and durability.

One of the avenues for sustainably improving concrete properties is by adding a natural admixture in ordinary concrete. In particular, natural gum has been recognized in prior studies as a potential natural substitute for synthetic admixtures, and preliminary investigations confirmed its favourable effects on some concrete properties. For instance, acacia Senegal, a Nigerian natural gum, was investigated in (Zakka et al., 2015) where concrete air content was found to decrease as natural gum fraction is augmented and workability, measured using flow table, increased with gum content, which proposes a potential for the use of natural gum in self-compacting concrete. This is highlighted in the more recent study in (Mbugua et al., 2016) in which it was showed that the so-called natural gum concrete provides more workability and longer setting times, measured using the Vebe test, than ordinary concrete.

In addition to the physical, mechanical and durability properties, the microstructural analysis is considered, in the present thesis, in determining the effect of the addition of a specific natural gum, precisely, Sudanese Arabic Gum Biopolymer as an admixture in ordinary concrete. Therefore, this detailed research has been conducted to assess the use of Arabic Gum Biopolymer in the concrete to create data that will contribute to the improvement in the quality of construction works.

The current thesis aims to demonstrate and evaluate the benefits of employing a particular variant of AGB as a natural additive material to a concrete mixture by measuring the effect of AGB on the relevant fresh and hardened properties of ordinary concrete at various ages. These properties, namely, initial setting time, workability, air content the fresh mix and soundness, capillarity, porosity, splitting tensile and flexural strength, compressive strength, rebound hummer and finally, the durability of the AGB added to concrete, are evaluated experimentally and through chemical composition and microstructural analysis. This work should aid to compare the influence of AGB

with that of existing additives which are known to improve strength and durability in ordinary concrete structures.

1.1.1 Problem Statement

Vegetal products are being used, increasingly, in industrial and building materials given their cost-effectiveness and the growing concern about the environment and sustainability. In particular, Arabic Gum Biopolymer has been widely used in various industries, including textiles, lithography, cosmetics, encapsulation, pharmaceuticals, and even in the food industry. However, its utilization in the construction field is limited. In one of the rare research study on the subject, Gum Arabic has been used as an additive in a binder to ceramic glazes, in order to increase the glaze mixture workability and fluidity and to help the clay adhere to the glaze before it is fired, thus decreasing the handling damage during manufacturing (Osman, 2008).

There are indications that AGB has a potential for being an ingredient for maintenance and an effective additive to the concrete mix that could improve some of the physical and mechanical properties of the fresh and hardened concrete (Onyelowe and Okafor, 2015). For instance, in addition to improving tensile and compressive strength, it is desirable to increase the fluidity and workability of the fresh mix and to decrease porosity and capillarity in order to improve concrete durability. Promoting the utilization of AGB in concrete technology as an admixture, retarder and water reducer, would generate an added value to the product, with significant economic and social impacts on the local communities where AGB is produced. The goal of this research has been to evaluate the performance of AGB on the fresh, physical and mechanical properties of ordinary concrete investigated at different ages and to determine the optimum percentage of Arabic Gum Biopolymer that will achieve the best improvement for each of these concrete properties. For this purpose, an experimental set-up was designed to determine the physical, mechanical and durability properties of the specimens of ordinary concrete made out of mixes with different fractions of AGB. XRF and XPS were used to determine the chemical analysis

followed by raman microscopy was used to offer qualitative and quantitative analysis for organic and inorganic specimens. The crystalline phases present in the concrete materials was analysed using X-ray Diffraction (XRD). Fourier Transformed Infrared Spectrometer (FTIR) was used to determine the bonding strength in funcational group. Thermo Gravimetric Analysis (TGA) was used to determine the reaction of mass or percentage of initial mass due to temperature, Scanning Electron Microscopy (SEM) and BET were utilized to study the microstructure properties of the AGB concrete.

1.2 Research Aim and Objectives

This research aims to create added value to the AGB, a sustainable natural (vegetal) material. In pursuit of this aim, it is necessary to demonstrate the benefits of added AGB on the engineering properties and durability of AGB concrete leading to improved performance of the ordinary concrete. For this purpose, the following objectives are targeted:

(a) To study the material properties and raw material of AGB and AGB concrete.

(b) To assess the effect of AGB on the fresh state, physical and mechanical properties of AGB concrete.

(c) To determine the optimum percentage of AGB with respect to the selected properties.

(d) To evluate the effect of AGB on durability of AGB concrete exposed to chloride, acid, carbonation and fire attacks.

1.3 Limitations of the study

This study is intended to explore the potential of using Arabic Gum Biopolymer produced in Sudan in concrete technology as an additive to improve the physical and mechanical properties of fresh and hardened concrete or as an element in

the composition of materials used in concrete technology. It has, thus, focused on the AGB product brought from Sudan. Moreover, this study has been limited to ordinary concrete, excluding, for instance, high performance concretes. Furthermore, the microstructure analysis was limited to X-ray fluorescence and XPS, Raman, X-ray diffraction, FTIR spectra, scanning electron microscopy and TGA.

1.4 Research Significance

Vegetal materials are increasingly being incorporated in the composition of industrial products materials are given their cost-effectiveness and the growing concern about the issues of sustainability and environmental protection. Along with this growing trend, the research has been intended to provide knowledge on the chemical, physical and mechanical properties of AGB concrete that may reveal potential applications in civil engineering and to promote the utilization of AGB, an abundant, sustainable natural material, on the fresh and hardened characteristics of ordinary concrete as a retarder and water reducer in concrete technology.

Improve the strength and durability performance of ordinary concrete by refining the pore structure and decreasing the permeability to external attacks in a cost-effective way using a natural product. Finally, create an added value to AGB, which generates socio-economic benefits to the local communities in AGB producing regions.

1.5 Research Approach

The research approach used was to:

(a) Carry a literature review on the utilization of natural materials, such as chemical and mineral admixtures, and their uses and effects on the different properties of concrete and other related construction materials.

(b) Select and prepare Arabic Gum Biopolymer, cement, fine aggregates and coarse aggregates based on their characteristics to determine the mix design and the process of the AGB concrete mixing.

(c) Use the various standard experimental procedures, such as ACI, ASTM, BS, EN, IS and RELIM, to help interpret the results of the experiments conducted on the modified concrete containing different percentages of the AGB.

(d) Examine several trial mixes and determine the fresh mix properties and hardened concrete physical and mechanical, durability and microstructure properties for ordinary concrete mixed with different amounts of AGB.

(e) Develop an appropriate schedule for the experimental program to investigate the modified concrete samples containing different fractions of the AGB.

(f) Conduct experimental work to evaluate the influence of AGB on the fresh and hardened, properties of ordinary concrete mixed with different amounts of AGB and compare the performance with the control specimen for each experiment.

(g) Carry out the analysis of the experimental finding and discuss the results. Draw conclusions and make recommendations on the applications of AGB as a new admixture material for concrete construction.

1.6 Thesis Layout

The thesis is divided into eight chapters. Chapter 1 presents the general background of the problem, aim and objectives of the study, research highlights, scope and limitations of this research. The significance and the approach of the study, the thesis outline and the layout have also been included in this chapter.

Chapter 2 presents a literature review on, (i) the natural gum materials and their properties, (ii) concrete admixtures and their physical and chemical properties, (iii)

durability of concrete and (iv), the microstructural characterization of concrete material.

Chapter 3 presents the research methodology steps which are the material preparation, the mix design and the detailed testing procedures focusing on the fresh mix properties and the physical and mechanical, durability and microstructure properties of hardened AGB-concrete.

The experimental results and their analyses are presented in Chapters 4, 5, 6 and 7. The main findings are relative to the compressive test, flexural and tensile strength tests, permeability test, porosity tests and the capillary and water absorption test. A discussion is given on the durability and microstructural characterizations of AGB concrete compared to ordinary concrete.

The conclusions are given in Chapter 8 recalls the findings and the contribution of this research study to existing knowledge. Some recommendations are also suggested for future research to improve the quality of concrete using natural admixture materials

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APPENDIX B

PUBLICATION

JOURNALS

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