

**PERFORMANCE OF GEOPOLYMER SELF COMPACTING CONCRETE
USING SPENT GARNET AS SAND REPLACEMENT**

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USING SPENT GARNET AS SAND REPLACEMENT

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Civil Engineering
Universiti Teknologi Malaysia

April 2018

ALHAMDULILLAH

*All Praise for Allah, Creator of This Universe
Thanks for The Precious Iman & Islam You Blessed on Me
Thanks for All the Strength and Knowledge You Granted on Me
And, Peace Be Upon the Holy Prophet Muhammad SAW.
Thanks*

I dedicated this work to:

My mother, **Hajja Qismah Mezher**, whose sacrifice;
My Father, **Alhaji Lateef Muttashar Alzuabidi**, whose support and encouragement;
And
My beloved wife, **Hoda Husseinpour Nasirmahaleh**, whose love and patience;
led to achieving my doctoral degree

ACKNOWLEDGEMENT

In the name of Allah, the Beneficent, the Merciful Who has created the mankind with knowledge, wisdom and power. I would like to express my thanks to Almighty **ALLAH** on the successful achievement of this research work and thesis.

At this moment, I express my honest and deep appreciation to my supervisors Dr. Mohd Azreen Mohd Ariffin, Professor. Madya Dr. Nazri Bin Ali and supervisor, Professor Ir. Dr. Hj. Mohd. Warid Bin Hj. Hussin for their honest advice and supervision supported during the whole of my studies. Their faith, patience, and intelligence have always been motivation for me throughout my career life.

My gratitude is also extended to the “Structures and Materials Laboratory” staff. Thank you for the support and friendship throughout the experimental works.

ABSTRACT

Robust engineering properties of spent garnet offer a recycling alternative to create efficient construction materials. Recycling of spent garnet provides a cost-effective and environmentally responsible solution rather than dumping it as industrial waste. In this context, the present work evaluated the capacity of spent garnet as sand replacement to achieve self-compacting geopolymer concrete. The self-compacting geopolymer concrete was prepared using ground granulated blast furnace slag whereas the river sand was replaced by spent garnet of varying contents in the range of 0 to 100% under constant Liquid/Binder mass ratio of 0.4. Experiments were carried out to evaluate the leaching performance, microstructure, physical and chemical behaviour of the spent garnet specimens. Furthermore, mix design combined with the fresh and hardened features of the spent garnet based self-compacting geopolymer concrete were performed. Performance evaluations of the developed self-compacting geopolymer concrete were made using various tests such as compressive, splitting tensile, flexural, durability and workability (slump, L-box, V-box and T50) consistent with the requirements and guiding principles of European Federation of National Associations representing concrete. Meanwhile, the morphology, bonding and thermal properties of self-compacting geopolymer concrete were determined using X-ray diffraction, field emission scanning electron microscopy, Fourier transform infrared spectroscopy, and thermo gravimetric analysis. Experimental results revealed an enhancement in the workability of the proposed self-compacting geopolymer concrete specimens due to the increase in spent garnet contents. However, the mechanical strength of the proposed self-compacting geopolymer concrete was discerned to be lower compared to the control sample at every garnet content ratio replacement stage. Concretes prepared with sand replaced spent garnet demonstrated excellent resistance to carbonation than the control sample. Based on the analysis, the results suggest that the spent garnet is proven to be a suitable replacement of sand.

ABSTRAK

Ciri-ciri kejuruteraan garnet terpakai yang kukuh menawarkan alternatif kitar semula untuk mencipta bahan pembinaan yang cekap. Kitar semula garnet terpakai menyediakan penyelesaian kos yang efektif dan bertanggungjawab terhadap alam sekitar berbanding dengan membuangnya sebagai sisa industri. Dalam konteks ini, kajian terkini menilai kemampuan garnet terpakai sebagai pengganti pasir untuk mendapatkan konkrit geopolimer terpadat sendiri. Konkrit geopolimer terpadat sendiri disediakan dengan menggunakan sanga relau bagas dikisar manakala pasir sungai digantikan dengan garnet terpakai pada pelbagai kandungan dalam julat 0 hingga 100% di bawah nisbah jisim Cecair/Pengikat malar 0.4. Kajian dijalankan untuk menilai prestasi larut lesap, mikrostruktur, tingkah laku fizikal dan kimia spesimen garnet terpakai. Selain itu, reka bentuk campuran digabungkan dengan ciri-ciri segar dan keras garnet terpakai daripada konkrit geopolimer terpadat sendiri. Penilaian prestasi konkrit geopolimer terpadat sendiri telah dibuat dengan menggunakan pelbagai ujian seperti mampatan, pemisahan tegangan, lenturan, ketahanan lasakan, dan keboleherjaan (ujian runtuhan, *L-box*, *V-box*, dan T50) selaras dengan keperluan dan prinsip-prinsip panduan Persekutuan Persatuan Kebangsaan Eropah yang mewakili konkrit. Sementara itu, sifat morfologi, ciri-ciri terma dan ikatan konkrit geopolimer terpadat sendiri ditentukan dengan menggunakan analisis pembelauan sinar-X, mikroskop elektron pengimbasan pancaran medan, spektroskop inframerah jelmaan Fourier dan terma gravimetri. Dapatan kajian menunjukkan terdapat peningkatan dalam keboleherjaan spesimen konkrit geopolimer terpadat sendiri akibat peningkatan kandungan garnet terpakai. Walau bagaimanapun, kekuatan mekanikal konkrit geopolimer terpadat sendiri yang dicadangkan adalah lebih rendah berbanding dengan konkrit sampel kawalan pada setiap peringkat penggantian nisbah kandungan garnet terpakai. Konkrit yang disediakan dengan garnet terpakai yang menggantikan pasir menunjukkan ketahanan yang sangat baik terhadap pengkarbonatan berbanding sampel kawalan. Berdasarkan analisis, hasil dapatan kajian menunjukkan bahawa garnet terpakai terbukti mampu menjadi pengganti pasir yang sesuai.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
Ca	-	Calcium
CaCO ₃	-	Calcium Carbonate
CaO	-	Calcium Oxide
C-A-S-H	-	Calcium Alumina Silicate Hydrate
CO ₂	-	Carbon Dioxide
GP	-	Geopolymer
GPC	-	Geopolymer Concrete
C-S-H	-	Calcium Silicate Hydrate
DTA	-	Differential Thermal Analysis
EFNARC	-	European Federation of National Associations Representing
FESEM	-	Field Emission Scanning Electron Microscope for Concrete
FTIR	-	Fourier Transform Infrared
GBFS	-	Granulated Blast Furnace Slag
GPC	-	Geopolymer Concrete
H ₂ SO ₄	-	Sulphuric Acid
MoE	-	Modulus of Elasticity
NaOH	-	Sodium Hydroxide
Q	-	Quartz
SiO ₂	-	Silica
SP	-	Super Plasticizer
TGA	-	Thermo Gravimetric Analysis

LIST OF SYMBOLS

m1	-	Mass of container
m2	-	Mass of container with fresh concrete
W	-	Percentage of water absorption
Wd	-	Weight of specimen dry
Ww	-	Weight of specimen wet
V	-	Volume of container

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Rapid industrial growth has witnessed the ever-increasing utilization of sand from rivers for various construction purposes, which caused an over-exploitation of rivers' beds and disturbed the eco-system. Numerous problems have emerged including the increase of river bed depth, lowering of the water table, increase of salinity and destruction of river embankments (Gourley,2003). Recently, intensive researches have proven that modified concretes obtained by incorporating waste materials can lead to sustainable product development. Such concrete structures not only allow for greener and environmentally sound construction but also protect the excessive consumption of natural fine aggregates that are non-renewable (Temuujin, 2010). Thus, proper use of fine aggregates in the concretes as alternative materials became an absolute necessity for the replacement of river sand. In this regard, utilization of spent garnets emerged as a promising alternative in its own right.

The so called “garnet” is a generic word that refers to an assemblage of multifaceted minerals of silicate compounds containing Calcium (Ca), Magnesium (Mg), Ferrous iron (Fe) or Manganese (Mn), Aluminium (Al), Chromium (Cr), Ferric

iron (Fe) or even Titanium (Ti) having analogous crystal lattice structures and varied chemical formulas (Castel,2010). Interestingly, the angular fractures and hardness properties of garnets together with their ability to be recycled make them advantageous for numerous abrasive applications. The common chemical composition of garnet is $A_3B_2(SiO_4)_3$ wherein the element “A” may be Ca, Mg, ferrous iron, or Mn, Al, Cr, ferric iron or Ti (Rodina, 2013). Garnets have major industrial uses such as water jet cutting, abrasive blast medium and powder, granule for water filtration, and other (Lindtner, 2014).

A comprehensive assessment on a major shipyard industry in the southern province of Malaysia revealed that the country imported approximately 2000 MT of garnets in 2013 alone, and a large quantity was dumped as wastes. Generally, abrasive blasting technique is used to prepare the surfaces for coating and painting (Roskill Information Services Ltd., 2000). This technique is used for the construction of vessels, ship maintenance and repair activities. Thus, blasting process creates large quantities of exhausted garnet wastes mixed with surface elements such as paint chips and oil. Such garnet wastes cause many environmental and health hazards like water contamination when these materials enter the waterways during flood or through runoffs. Therefore, spent garnets pose a threat to the ecological balance and biodiversity. Garnets can be reused about 3 to 5 times keeping their overall properties intact. Garnets are discarded from the shipyards and nominated as “spent garnet” Moreover, these recycled garnets degrade at a level beyond which they are non-reusable for abrasive blast purposes. Afterwards, these inoperative garnets are abandoned from the shipyard and designated as “spent garnet” (Garnett, 2013). Recently, it has been recognized that utilization of these spent garnets as replacement for fine aggregates in self-compacting geopolymer concrete may offer greener alternative construction materials to the ordinary Portland cement (OPC) based concrete.

Universally, Ordinary Portland Cement (OPC) possessing excellent mechanical properties, moderately cheap and easy accessibility makes it the most commonly used binder for construction materials production. Thus, OPC based

concretes is preferred in diversified purposes (Davidovits, 1991). Nonetheless, OPC manufacturing leads to the depletion of natural habitats, manufacturing of fossil fuels, and substantially high CO₂ emissions which our planet cannot afford to anymore. To overcome those threats, many dedicated efforts have been made to search for efficient alternative substances such as alkali-activated materials interpreted as geopolymer in short GP. The cost production of geopolymer concrete 1.7 % higher than OPC for the same grade (Thaarrini, 2016).

These alternative substances are proven to be advantageous for sustainable development when industrial by-products are partially applied as precursor matter as a substitute of main raw mineral binder including OPC. Moreover, the final product exhibits improved characteristics than OPC based concrete dependent on the implemented raw minerals and alkali activations. Factors such as the poorer heat of hydration, rapid development of early strength, formation of stronger aggregate to matrix interface, poorer thermal conduction (TC), and elevated resistance of acid and fire (Provis, 2010) also influence considerably the overall properties of the ultimate products. Generally, alkali activated materials are classified in two categories: (a) a high calcium system with granulated blast furnace slag as a usual precursor, where gel of calcium alumina silicate hydrate nature is the major product of reaction, (b) a low calcium product having Class F fly ash (FA) and metakaolin as constituent raw materials, where gel of sodium alumina silicate hydrate kind in the form of three-dimensional network is produced as the main product of reaction.

Categorically, the flow ability of self-compacting concretes' (SCC) under their own weight without requiring any exterior compaction vibration has modernized the placement of concretes. A group of researchers from Japan in the late 1980s first introduced the concept of SCC (Domone, 2006). It was established that a greatly workable concrete such as SCC display a flow under its own weight via constrained segments in the absence of any segregation or bleeding. Such concretes must possess comparatively a small yield to guarantee enhanced flow capacity, reasonable viscosity to oppose separation and bleeding. Furthermore, it must retain the homogeneity during

transport, placement and curing to guarantee sufficient structure performance and long-standing endurance.

Despite many researches toward sand replacements for concrete infrastructures, exploitation of spent garnet waste as construction material product is seldom focussed. Considering those notable engineering properties of spent garnet waste this research explored the feasibility of incorporating different levels of spent garnet as a replacement for river sand to achieve an enhanced self-compacting geopolymer concrete (SCGPC). self-compacting geopolymer concrete specimens were thoroughly characterized to determine their compressive, flexural, workability durability and microstructure as a function of varying percentages of spent garnet inclusion.

1.2 Problem Statement

There are three main research questions in this study:

1. What are the effects of spent garnet on the fresh and hardened characteristics of the self-compacting geopolymer concrete in terms of workability and mechanical strength.
2. What are the effects of spent garnet on self-compacting geopolymer concrete durability such as carbonation, sulphate attack, acid attack.
3. What are the effects of spent garnet on the morphology of self-compacting geopolymer concrete such as bonding and thermal analysis.

1.3 Aim and Objectives

This study aims at developing self-compacting geopolymer concrete incorporating spent garnet as fine aggregate. three objectives were formulated to achieve the aim of the study, they are:

- 1- To determine the physical and chemical properties of spent garnet according to standard requirements of sand set by EFNARC, ASTM and BS.
- 2- To determine the effects of spent garnet on the fresh and hardened characteristics of the self-compacting geopolymer concrete in terms of workability and mechanical strength.
- 3- To determine the effects of spent garnet on self-compacting geopolymer concrete durability such as carbonation, sulphate attack, acid attack and microstructural properties.

1.4 Scope of the Research

This work conducted several experiments (for synthesis, characterization and performance evaluation) and mainly focused to develop the sustainable SCGPC containing spent garnet with varying level (25%, 50%, 75% and 100%) of replacement to river sand. The properties of the constituent concrete materials including leaching behaviour, carbonation, thermal and mechanical characteristics and microstructures of the garnet were examined.

The workability, mechanical strengths, deformation (modulus of elasticity) and durability characteristics of the developed SCGPC were evaluated to make a comparison with that of traditional concretes. Tests such as L-Box, Slump, U-Box, T50, compressive strengths, flexural strengths, indirect tensile strengths, drying shrinkage, modulus of elasticity, carbonation, acid and sulphate resistance were carried out to determine the performance of formulated SCGPC. The hardened SCGPC with optimum composition was selected to examine the crystallinity, microstructure, bonding and thermal properties using X-ray diffraction, field emission scanning electron microscopy, fourier transform infrared spectroscopy, thermo gravimetric analysis/differential thermal analysis.

1.5 Significance of the Research

Certainly, the use of spent garnet in self-compacting geopolymer concrete as an alternative to river sand is beneficial in terms of saving the environmental pollution and over exploitation of natural resources. Most of the recycling efforts that limits the wastes disposal can be overcome by properly using the spent garnets in making SCGPC (Lottermoser, 2011). Use of spent garnets directly contributes to the sustainable development, cost-effective way of SCGPC manufacturing and preservation of natural sand from further degradation. Currently, enormous amount of spent garnet is regularly disposed and used for land filling that require high transportation cost and is labour intensive. This not only pollutes the environment but have no monetary gain. Present work will solve these existing problems by systematically incorporating the spent garnet in place of sand to prepare new composition of sustainable SCGPC. This kind of SCGPC will be economically viable because of high abundance, non-toxic nature and cost-effectiveness of spent garnets as main constituent of self-compacting geopolymer concrete. It is demonstrated that spent garnets are potential substitute material to river sand in the building and structural engineering. Thus, use of spent garnet in place of fine aggregates to make concrete will avoid the over-usage of natural sand. This research effort is expected to

bring modernization in the Malaysian construction industries, encourage builders and engineers to use eco-friendly spent garnet based SCGPC than the conventional one made of natural river sand.

1.6 Thesis Organisation

The present thesis is composed of seven chapters as follows:

Chapter 1 provides a brief background and overview of the research to identify the research gap, clarifies the problem statement and rationale of the research. Based on the problem to be solved it sets the goal and relevant objectives. Furthermore, it discusses the research scope and significance.

Chapter 2 presents a comprehensive literature review to justify the problem statement. Past development in SCGPC, ongoing activities in the field of spent garnet based concrete production and future trends in SCGPC based on spent garnets as a replacement to river sand is emphasized.

Chapter 3 describes the experimental research methodology in detail starting from raw materials selection, GPC preparation using spent garnet (fine aggregates) of varying contents by replacing river sand, SCGPC composition optimization, samples characterizations and performance evaluations. All the tests and methods applied to determine the fresh and hardened properties of synthesized SCGPC and their durability issues are explained to fulfil the proposed research objectives.

Chapter 4 presents the experimental results in terms of analyses, discussions, evaluations and comparisons with other works on similar SCGPC. Results on physio-

chemical properties of spent garnets and their effects on the fresh as well as hardened properties of SCGPC are highlighted. Results obtained on workability using the tests such as slump, L-box, V-box, T50 and hardened properties are discussed in terms of compressive, flexural, tensile strength, DS and modulus of elasticity.

Chapter 5 explains and discusses the results obtained from different tests on durability performed on control specimen as well as spent garnet based geopolymer concrete. Results from the durability tests on SCGPC such as drying shrinkage, water absorption, accelerated carbonation, resistance to acid and sulphate attack are investigated.

Chapter 6 presented the results on thermal properties, bonding vibrations, crystalline structures, surface morphology and microstructures of spent garnets obtained via TGA/DTA, FESEM, FTIR and XRD analysis. Furthermore, results on microstructure studies of SCGPC are presented at 6 months and above of strength development.

Chapter 7 concludes the overall performance of spent garnet as sand replacement in self-compacting geopolymer concrete, major contributions, and novelties of the present study.

Chapter 8 concludes the conclusion of research objectives and some suggestions are underlined as recommendations for further research in this frontline area of civil engineering.

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