HIGH PERFORMANCE CONCRETE UTILIZING METAKAOLIN AND SPENT GARNET

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DEDICATION

To my beloved parents for their endless support and love.
To my siblings who always encourage me along the road.
To my supervisor for all the guidance and understandings.
To my close friends for always being there.

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ABSTRACT

This study deals on the utilization of metakaolin and spent garnet as part of cementitious and fine aggregates replacement in high performance concrete (HPC). HPC offers many benefits especially towards application of structures which sustain higher loads and exposed to harsh environment at the same time such as piers. HPC usually been produced by applying supplementary cementitious material as an admixture to enhance the quality of HPC. Metakaolin is known as one of the common material that has been proven to produce good qualities of HPC. Spent garnet is one of the industrial waste materials which had been recognized as suitable fine aggregates substitution in concrete. Apart from sand mining issue which had been highlighted, excessive amount of spent garnet in the landfill had also seems to jeopardize the environment. Thus, the study on the utilization of spent garnet and metakaolin in producing HPC is performed. Physical properties test of the materials had been conducted and trial mixes had been executed afterwards with replacement of spent garnet in percentage amount of 10%, 20%, 30%, 40%, 50% and 60% by weight. The workability test results showed that at the replacement of 60%, the fresh concrete bled. Compressive strength, flexural strength, splitting tensile strength and modulus of elasticity tests were carried out to determine mechanical properties of the mix proportion. The morphology of the HPC was identified by completing Scanning Electron Microscope (SEM) with Energy Dispersive X-Ray Analysis (EDX) and X-Ray Diffraction Analysis Test (XRD). The durability test was conducted to observe the resistance of HPCM and HPCMG50 towards chloride penetration and elevated temperature test. HPC with 50% of spent garnet replacement (HPCMG50) indicated the highest value of compressive strength with 92.3 MPa as compared to 65.4 MPa for HPC without any spent garnet replacement (HPCM). As conclusion, this study found that 50% utilization of spent garnet is effective in producing HPC with better mechanical properties and chloride resistance. Hence utilization of 50% of spent garnet as fine aggregates replacement is a good approach in fighting the issue of sand deficit as well as betterment of landfill management.

ABSTRAK

Kajian penggunaan metakaolin dan sisa garnet sebagai bahan gantian simen dan agregat halus dalam konkrit berprestasi tinggi (HPC) telah dijalankan. HPC selalunya dihasilkan melalui penggunaan bahan simen tambahan sebagai bahan campuran untuk meningkatkan kualiti HPC. Metakaolin dikenali dan telah dibuktikan sebagai salah satu bahan yang sering digunakan dalam menghasilkan HPC yang berkualiti. Sisa garnet merupakan salah satu bahan buangan industri yang telah dikenalpasti sebagai bahan yang sesuai untuk digunakan sebagai bahan gantian agregat halus dalam konkrit. Selain daripada isu perlombongan pasir, lambakan sisa garnet di tapak pelupusan juga dilihat sebagai perkara yang dapat menjejaskan alam sekitar. Oleh itu, kajian mengenai penggunaan sisa garnet dan metakaolin dalam menghasilkan HPC dijalankan. Ujian sifat fizikal bahan-bahan ini dan seterusnya percubaan mendapatkan campuran konkrit dengan penggantian peratusan jumlah sisa garnet berdasarkan berat sebanyak 10%, 20%, 30%, 40%, 50% dan 60% telah dijalankan. Ujian kebolehkerjaan menunjukkan berlakunya penjujuhan pada penggantian sisa garnet sebanyak 60%. Ujian kekuatan mampatan, kekuatan lenturan, kekuatan tegangan dan modulus keanjalan dijalankan bagi mendapatkan sifat mekanikal campuran konkrit terbabit. Morfologi HPC dikenalpasti melalui ujian peingimbasan mikroskop electron (SEM) bersama ujian analisis penyebaran tenaga X-Ray (EDX) dan ujian analisis pembelauan X-Ray (XRD). Ujian ketahanan telah dijalankan bagi mengenalpasti tahap rintangan HPC terhadap penembusan klorida dan suhu tinggi. HPC dengan penggantian 50% sisa garnet menunjukkan kekuatan mampatan tertinggi dengan nilai 92.3 MPa berbanding 65.4 MPa bagi HPC tanpa sebarang gantian sisa garnet Sebagai kesimpulan, kajian ini mendapati bahawa penggantian sisa garnet sebanyak 50% adalah efektif dalam menghasilkan konkrit berprestasi tinggi yang lebih berkualiti dari segi sifat mekanikal dan rintangan klorida. Oleh itu, penggantian50% sisa garnet adalah merupakan salah satu pendekatan yang baik dalam menangani isu penguranagn pasir disamping penambahbaikan pengurusan tapak pelupusan.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CBR	-	California Bearing Ratio
CMT	-	Chloride Mitigation Test
CRM	-	Cement Replacement Material
DMDA	-	Densifies Mixture Design Algorithm
EDX	-	X-ray Spectroscopy
ECC	-	Engineered Cementitious Composite
GGBS	-	Ground Granulated Blast Furnace Slag
HPC	-	High Performance Concrete
HPCM	-	High Performance Concrete Utilizing Metakaolin
HPCMG	-	High Performance Concrete Utilizing Metakaolin and Spent Garnet
HPCMG50	-	High Performance Concrete Utilizing Metakaolin and 50% Spent Garnet Replacement
HSC	-	High Strength Concrete
ITZ	-	Interfacial Transition Zone
LOI	-	Loss Of Ignition
MIP	-	Mercury Intrusion Porosimetry
MS	-	Malaysian Standard
OPC	-	Ordinary Portland Cement
PSA	-	Particle Size Analysis
RCPT	-	Rapid Chloride Penetration Test
SEM	-	Scanning Electron Microscopic
SG	-	Specific Gravity
SHRP	-	Strategic Highway Research Program
SSD	-	Saturated Surface Dry
TG	-	Thermogravimetry
TLCP	-	Toxicity Characteristic Leaching Procedure

UPV	-	Ultra Sonic Pulse Velocity
U.S EPA	-	United States Environmental Protection Agency
XRD	-	X-ray Diffraction
XRF	-	X-ray Fluorescence

LIST OF SYMBOLS

°C	-	Celsius
$AgNO_3$	-	Silver Nitrate
K_2CrO_4	-	Pottasium Chromate
AgCl	-	Silver Chloride
AgOH	-	Silver Hydroxide
$AgNO_3$	-	Silver Nitrate
K_2CrO_4	-	Pottasium Chromate
AgCl	-	Silver Chloride
AgOH	-	Silver Hydroxide
$AgNO_3$	-	Silver Nitrate
Al_2O_3	-	Aluminum Oxide
$Ca(OH)_2$	-	Calsium Hydroxide
C_3S	-	Alite
C_2S	-	Belite
C-S-H	-	Calcium Silicate Hydrate
$Ca(OH)_2$	-	Calsium Hydroxide
C_3S	-	Alite
C_2S	-	Belite
Fe	-	Iron
Fe_2O_3	-	Iron (III) Oxide
H_2	-	Hydrogen
H_2O	-	Water
K_2O	-	Pottasium Oxide
MgO	-	Magnesium Oxide
MnO	-	Manganese
Na_2O	-	Sodium Oxide
O_2	-	Oxygen
OH	-	Hydroxide
P_2O_5	-	Phosphorus Pentoxide
SiO_2	-	Silicon Oxide

TiO_2	-	Titanium Dioxide
ZnO	-	Zinc Oxide

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Rapid changes in the construction world have created an urge for exploration of various type of concrete to suit the need of the structures to be built. Nowadays, the demand of concrete does not only concern on high strength but the needs of concrete that will provide a longer lifespan of the structure. In order to achieve this, high-performance concrete which hold the ability to perform well compared to conventional concrete offers a better opportunity to fulfill the requirement.

High performance concrete (HPC) has been defined by American Concrete Institute (ACI) as concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practice. HPC does not only bear high stresses but also beneficial in high durability which is one of the important key elements in a safe structure. Previously, the design of the concrete mixes used in concrete focus on the strength and workability while less attention was given to the durability. This leads to deterioration, corrosion, bleeding, efflorescence or cracks that appear commonly within few years of construction (P.K Chang *et al,* 2001). Due to this, various studies have been conducted all around the world aiming to achieve a better quality of concrete that not only focus on its strength but also its resistance toward the harsh environment. To achieve this, the design of the HPC mixes does not only rely on additions of appropriate amount of chemical admixture and pozzolanic materials but also the substitution of microaggregate that contributes to filling effect thus will improve compactness of the concrete and slows down the diffusion of ions (Y.N Chan *et al,* 2000). Alongside this, silica fume has also been widely used in producing HPC (Rana *et al.,*2016). However, in this study usage of silica fume is not significance as metakaolin as supplementary cementitious material. Many researches have stated that the usage of metakaolin as supplementary cementitious material have increases compressive strengths, resistance towards chemical attack and enhance workability (Antoni M. *et al,* 2012), (V. P.Dinkar *et al,* 2013) and (Sabale V.D *et al,*2014). Hence, in this study, metakaolin as part of cementitious material while garnet as part substitution of fine aggregates were used in producing HPC.

Other than supplementary cementitious material (SCM), replacement of fine aggregates is also an effective approach in producing HPC. Garnet, a material that had been utilized in many industrial areas especially as abrasive blasting, abrasive powders, waterjet cutting and water filtration. Its angular fractures, relatively high hardness and specific gravity, chemical inertness and its ability to be recycled making it ideal for these industry applications (Olson, 2016). Upon achieving the recycle period, garnets will be treated as waste material and to be treated in the landfill. These garnets are now addressed as spent garnet. As spent garnet is no longer beneficial, it will be dumped in the landfill and with time the waste will affect the environment. Spent garnet can threatened ground water quality when this material entered the waterways through surge runoffs (Aletba *et.al,* 2018). Taking this as a factor has initiated the utilization of spent garnet as fine aggregates replacement materials in concrete Iqbal (2018) and (Muttashar *et al.,* 2018). Both studies have shown positive results with replacement of spent garnet as fine aggregates at 25% and 40%. Hence the utilization of spent garnet as part of material replacement for fine aggregates in producing HPC is a good prospect to be explored.

The development of HPC has opened an exploration path towards utilizing various materials to produce HPC. This development has led to the extensive usage of materials to their full potential in order to produce new material that will sustain a longer life cycle making it more ecological (Aïtcin, 2003). Despite many researches had been conducted in utilizing various materials in producing HPC, the utilization of garnet as fine aggregates in HPC and metakaolin as supplementary cementitious material has not been highlighted. Thus, a study on this is reasonable in identifying the suitability of these materials to be utilized in HPC. The study will focus on the properties of the materials used, mechanical and chemical properties, morphology and durability of the HPC.

1.2 Problem statement

High performance concrete has been applied all over the world in many structures. Due to its ability to resists high compression stresses along with its excellence in performance, high performance concrete seems to provide great solution towards construction in producing better quality of structure. As most concrete structures are designed for 50 years of age traditionally, applying high performance concrete in some structures has expanded the life span of the structures in design and built a service life of 100 years (P. Kumar Mehta, 2004). Consequently, many studies have been conducted implementing various materials to enhance the understanding of high-performance concrete behavior. One of the well-known and common materials used is metakaolin that had been applied as supplementary cementitious material for high performance concrete and other different types of concrete. Likewise, studies on utilizing garnet in producing geopolymer concrete and high strength concrete had been conducted and these studies had indicated the positive results. However, the utilizing of both materials metakaolin and garnet had not yet been highlighted thus it is relevance to combine these materials in producing high performance concrete.

River and mining sand have been known as one of the main materials in producing concrete worldwide. Its properties provide a suitable condition to be utilized as fine aggregates in the concrete. As construction field grow rapidly, the demand of natural minerals including sand have increase intensely. In order to produce more sand to meet the demand of the industry, the process of sand mining from the water bodies had been conducted excessively. The phenomenon does not only harm the stabilization of the riverbank, but the ecology system and environment were also impacted. As one of the rapid developing country, Malaysia too has been impacted with sand mining issue (Appendix A). In 2010, 1.17 billion metric tons of sand and gravel out of 2.76 billion metrics of natural mineral in total has been used in Malaysia (Umara et al., 2016)

As the sand mining issue had been a continuous concern with time, many studies had been conducted all over the world focusing on producing a better quality of concrete while minimizing the usage of this natural resource by replacing it with other materials. These materials included waste product from industrial and construction. Among these waste materials is spent garnet that is used for sandblasting, water jet cutting and water filtration granules. In 2013, assessment on Malaysia shipyard industry disclose that 2000 million tons of garnet had been imported to the country and massive amount of the quantity was dumped as waste (Muttashar *et al.,* 2018). These spent garnets will end up in landfill and needed to be managed properly to ensure the safety of environment. Therefore, the utilization of spent garnet as fine aggregates had been identified as a positive contribution to decrease amount of spent garnet in landfill and producing better quality of concrete at the same time.

1.3 Aims and Objectives

This study aims for developing high performance concrete utilizing metakaolin as supplementary cementitious material and garnet as partial replacement of fine aggregates and to identify its performance. Three objectives had been outlined to accomplish the aim as listed:

1. To design on optimum concrete mix of HPC utilizing metakaolin and spent garnet.
2. To investigate physical, mechanical and morphology properties of HPC utilizing metakaolin and spent garnet.
3. To study the durability on chloride penetration and elevated temperature exposure of HPC utilizing metakaolin and spent garnet

1.4 Significance of Study

Evolution of construction field has necessitated production of better type of concrete that can resist harsh environment thus sustain structure’s long-life span. The utilization of garnet as fine aggregates in the study will reduce a great amount of sand required in the concrete mix. This will be a positive contribution in fighting the struggling issue faced from sand mining operations that jeopardize the environment. The high bearable of compression stresses and more durable of the high-performance concrete utilizing garnet and metakaolin will benefits in applying the concrete to produce a better structure that will sustain high compression stresses while resisting harsh environment that can prolong the structure's life span. The morphology study of the concrete will produce better understanding of high-performance concrete utilizing garnet and metakaolin. In this study, the high-performance concrete produced was also tested for chloride penetration and its changes when exposed to elevated temperature up to 800°C. This will be beneficial in providing data to understand its performance thus provide a reference in design works.

1.5 Scope of Study

Scope of study for the research consists of producing high performance concrete utilizing metakaolin and spent garnet as supplementary cementitious material and fine aggregates replacement. All testing procedures were conducted in accordance of several guidelines which are Malaysian Standard (MS), British Standard (BS), American Society for Testing and Materials (ASTM) and suggested practices by previous studies. Sand, spent garnet and metakaolin used in the studies were tested for their physical properties including specific gravity, density, water absorption and sieve analysis. The investigation on metakaolin and spent garnet were then proceeded with SEM testing in order to understand the shape of their particles. Study on mechanical properties testing of compressive strength test was conducted for 3 cube samples each of HPC with metakaolin (HPCM) and HPC with metakaolin and spent garnet replacement by percentage (HPCMG). Flexural strength test with 3 prism specimens for each type, splitting tensile strength and modulus of elasticity test with 3 cylindrical specimens were conducted for selected optimum mix HPC with metakaolin and HPC with metakaolin and spent garnet replacement were then conducted. Scanning Electron Microscopic (SEM), X-ray Diffraction (X-RD) and X-ray Spectroscopy (EDX) were also conducted to understand the morphology of these samples. Study on durability for elevated temperature test limited till 800°C were executed for total of 24 cubic specimens for both HPCM and HPCMG. Changes on physical, colour, appearance of cracks and spalling were observed and recorded. Residual compressive strength and mass loss of specimens after exposed to elevated temperature were also conducted. Colorimetric test was then executed in order to understand chloride penetration towards HPCM and HPCMG. Total of 12 cubic specimens were used to observe the penetration before the specimens were then tested for reduction of compressive strengths after exposure of chloride. Durability towards chloride resistance in this study was limited to 120 days of chloride exposure.

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