THE EFFECTS OF SPENT GARNET IN HIGH STRENGTH CONCRETE SUBJECTED TO ELEVATED TEMPERATURE

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy (Structure and Material)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MAY 2018

DEDICATION

To my parents

Khiyon bin Abdul Kadir and Nor Beezah binti Hazmah

To my siblings, brother-in-laws, nieces and my love

Khirun Nissah, Nurul Aisah, Noor Azeyah, Nor Hanim, Mohamad Raffik, Mohd Shaifulizam, Khairool Aizat, Tengku Amirul, Mohd Fariq, Sophie Inayya, Aaira Annysa and Siti Nurshatila

ACKNOWLEDGEMENT

First and foremost all praise is to Allah (S.W.T) for the knowledge to make this research possible and overcome the hard time during the study.

I like to express my sincere appreciation and gratitude to my kind supervisors, Dr. Mariyana Aida binti Abd Kadir for her moral support, guidance, encouragement, friendship and patience throughout the research period. Without her guidance and advice, this thesis would not been the same present here. Besides that, I would like to extend my gratitude to my co-supervisor, Assoc. Prof. Dr. Abdul Rahman bin Mohd Sam and Dr. Nor Hasanah binti Abdul Shukor Lim for their generous time, motivation and discussion during this study. I am thankful to the staff of Materials and Structures Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM) for helping to my various laboratory works. My thanks also go to my research colleagues and friends who have provided assistance at various occasions.

Most importantly, my special thanks to my beloved parents, siblings and love for their support, sacrifice, encouragement, and prayer.

Thank you for everything.

ABSTRACT

The ability of garnet to be recycled makes garnet suitable for many industrial purposes. When the recycled garnet can no longer be reused in the ship cleaning process, garnet is removed from the shipyards and named as "spent garnet". This has resulted in millions of tons of spent garnet disposed in landfill, quarries, oceans and rivers, thus causing environmental problems. The rapid growth of construction industry has leading to the over exploitation of riverbeds. This scenario affects the environment which includes reduction of water quality and destabilization of the stream bed and banks. In this study the spent garnet was used as sand replacement in high strength concrete production. Several laboratory tests were done to determine the characteristics of spent garnet in terms of physical and chemical properties. Trial mix design and evaluation on fresh and hardened properties of high strength concrete were examined to achieve concrete strength 60 MPa at 28 days. Series of the concrete were prepared with a replacement of 0%, 20%, 40%, 60%, 80% and 100% by using spent garnet as a sand replacement with a water cement ratio of 0.33 and 0.33% of superplasticizer from the weight of cement was added to get the desired slump 60-180 mm. Workability of the concrete was studied in addition to hardened properties and durability of the concrete at ambient and elevated temperature. Furthermore, microstructural test which is Scanning Electron Microscopy (SEM) also was done in this research. Finally, the effect of concrete cover when exposed to elevated temperature and the bonding effect between concrete and steel at ambient temperature was determined. Results showed that at 20% and 40% replacement, the compressive strength of the concrete at 28 days were 62.55 MPa and 63.91 MPa, respectively, which is 3.8% and 6% higher than high strength concrete (HSC). High strength concrete mix consisting of 40% spent garnet using different concrete cover thickness subjected to elevated temperature and bonding effect with steel was investigated. From the fire test, 40% of spent garnet gives slightly better protection for steel bar when exposed to elevated temperature compared to HSC. For pull-out test, the results shows that using 40% of spent garnet gives higher bond strength compared to HSC. The failure mode for 50 mm concrete cover shows pull-out failure while 20 and 37.5 mm concrete cover shows splitting failure. Considering the test results, 40% of spent garnet as sand replacement in high strength concrete showed excellent performance in term of strength of concrete subjected to fire.

ABSTRAK

Keupayaan garnet untuk dikitar semula menjadikannya sesuai untuk kegunaan di industri. Apabila garnet yang dikitar semula tidak lagi boleh digunakan semula dalam proses pembersihan kapal, garnet dikeluarkan dari limbungan kapal dan dinamakan sebagai "garnet terpakai". Ini telah menyebabkan berjuta-juta tan garnet dibuang di tapak pelupusan sampah, kuari, lautan dan sungai, sehingga menyebabkan masalah alam sekitar. Pertumbuhan pesat industri pembinaan telah membawa kepada eksploitasi sungai. Senario ini akan memberi kesan kepada persekitaran yang merangkumi pengurangan kualiti air dan ketidakstabilan dasar sungai dan tebing sungai. Kajian ini menggunakan garnet terpakai sebagai pengganti pasir dalam pengeluaran konkrit kekuatan tinggi. Beberapa ujian makmal dilakukan untuk menentukan ciri-ciri garnet terpakai dari segi sifat fizikal dan kimia. Reka bentuk dan penilaian campuran percubaan pada sifat konkrit segar dan keras dari konkrit kekuatan tinggi telah diperiksa untuk mencapai kekuatan konkrit 60 MPa pada 28 hari. Beberapa bancuhan konkrit disediakan dengan penggantian 0%, 20%, 40%, 60%, 80% dan 100% dengan menggunakan garnet terpakai sebagai pengganti pasir dengan nisbah simen air 0.33 dan superpemplastik 0.33% dari berat simen ditambah untuk mendapatkan kejatuhan yang diingini 60-180 mm. Kebolehkerjaan konkrit dikaji sebagai tambahan kepada sifat-sifat yang telah mengeras dan ketahanan konkrit pada suhu bilik dan suhu tinggi. Selain itu, ujian mikrostruktur iaitu Pengimbasan Mikroskop Elektronik (SEM) juga telah dilakukan dalam kajian ini. Akhirnya, kesan penutup konkrit apabila terdedah kepada suhu tinggi dan kesan ikatan antara konkrit dan keluli pada suhu bilik ditentukan. Keputusan menunjukkan bahawa pada 20% dan 40% penggantian, kekuatan mampatan konkrit selama 28 hari adalah 62.55 MPa dan 63.91 MPa iaitu 3.8% dan 6% lebih tinggi daripada konkrit kekuatan tnggi (HSC). Campuran konkrit kekuatan tinggi yang terdiri daripada 40% garnet terpakai menggunakan ketebalan penutup konkrit yang berbeza tertakluk kepada suhu tinggi dan kesan ikatan dengan keluli dikaji. Dari ujian kebakaran, 40% garnet terpakai memberi perlindungan lebih baik untuk tetulang keluli apabila terdedah kepada suhu tinggi dibandingkan dengan HSC. Untuk ujian tarikan, keputusan menunjukkan bahawa penggunaan 40% garnet terpakai memberikan kekuatan ikatan yang lebih tinggi berbanding dengan HSC. Mod kegagalan untuk penutup konkrit 50 mm menunjukkan kegagalan tarikan manakala penutup konkrit 20 dan 37.5 mm menunjukkan kegagalan pemisahan. Dari ujian ini, 40% garnet terpakai sebagai pengganti pasir di dalam konkrit kekuatan tinggi menunjukkan prestasi cemerlang dari segi kekuatan konkrit apabila terdedah kepada api.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
XRF	-	X-Ray Fluorescence
SEM	-	Scanning Electron Microscopy
UPV	-	Ultrasonic Pulse Velocity
SiO_2	-	Silicon dioxide
Al_2O_3	-	Aluminium oxide
Fe_2O_3	-	Iron (iii) oxide
CaO	-	Calcium oxide
MgO	-	Magnesium oxide
Na_2O	-	Sodium oxide
MnO	-	Manganese (ii) oxide
CrO	-	Chromium (ii) oxide
SP	-	Superplasticizer
WRA	-	Water reducing agent
HRWR	-	High-range water reducer
NC	-	Normal Concrete
HSC	-	High Strength Concrete
HSSGC	-	High Strength Spent Garnet Concrete
SSD	-	Saturated-Surface Dry
OPC	-	Ordinary Portland Cement

LIST OF SYMBOLS

C_{nom}	-	Nominal concrete cover
C_{min}	-	The minimum cover
ΔC_{dev}	-	10 mm or can reduced to 5 mm
A_b	-	Area of bar
d_b	-	Diameter of the bar
f_s	-	Stress in the bar
P_{Max}	-	Maximum pull-out load
L_d	-	Embedded bar length
A	-	Mass of oven dry specimen
B	-	Mass of pycnometer filled with water
C	-	Mass of pycnometer filled with specimen and water
S	-	Mass of saturated surface dry specimen
p	-	Density of the concrete
m	-	Mass of the concrete
V	-	Volume of the concrete samples
$A1$	-	Oven-dried mass of sample
$B1$	-	Surface dried mass of sample
fc	-	Compressive strength
F	-	Maximum load
Ac	-	Cross section of the specimen
fc_f	-	Flexural strength
P	-	Maximum applied load
L	-	Supported span
b, d	-	Lateral dimension of the specimen
fc_t	-	Splitting tensile strength
$d1$	-	Cross-sectional dimension of the specimen
E	-	Modulus of elasticity (GPa)

σ	-	Stress (MPa)
ε	-	Strain
f'_c	-	cylinder compressive

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is a growing country with the aim of achieving developed nation status by the year 2020. Various activities consisting of industrial, socio-economic and construction sector are being actively planned and carried out to realize this vision. Therefore, construction sector may be taken into consideration as one of the most critical industries in Malaysia to maintain the general economic growth in Malaysia through providing the infrastructure needed to support the economic development activities. The rapid growth of this sector consequently required high amount of production and consumption of construction minerals such as coarse aggregates (rock) and fine aggregates (sand). However, the use of a large amount of these construction minerals has led to various environmental issues.

It is generally known that river sand is not a renewable natural resource and in some part, river sand has been exploited excessively which can cause negative impact to the environment. The challenge for the civil engineering group with the idea of economic improvement includes the utilization of waste materials and a by-product at minimum environmental impact and cost. Therefore, accomplishing an eco-friendly environment, in an economical manner, through reusing of waste materials in construction sector have become essential worldwide issues. Previous research has proven that the usage of waste materials and a by-product of industries in construction as materials in concrete appear to offer adequate solution to this problem. For example, several researches have been conducted in the area of adding and replacing sand with slag, bottom ash and recycle of aggregate to improve mechanical strength and durability of concrete. However, the increasing amount of new waste materials or new by-product industrial waste has reduced the space for landfill. These problems of landfill and environmental issues have become the major reason for extensive research to utilize the use of waste materials in concrete production.

It is interesting to know that spent garnet is a material used for sandblasting ships in southern part of Malaysia. Generally, garnet is a widespread mineral found in a crystal metamorphic rock that is characterized by a variety of chemical elements and colours. The ability of garnet to be recycled 3 to 5 times and the hardness of garnet make it suitable in abrasive work. Finally, when the recycled garnet can no longer be reused in the abrasive blasting process, garnet is removed from the shipyards and named as “spent garnet” (Gorill and Lindsay, 2003). The non-use of spent garnet has become an industrial waste and has filled the space of landfill.

Previous study has considered the utilization of spent garnet as fine aggregates replacement in a geopolymer concrete (Habeeb *et al.,* 2017). It was reported that replacing 25% of spent garnet as fine aggregates in a geopolymer concrete could be considered as optimum for mechanical properties and flow ability. Although the use of spent garnet has already been studied by several previous researchers, the utilization of spent garnet in geopolymer is low compared to huge amount of disposal.

In order to maximise the utilization of spent garnet there is need to carry out an extensive research on the chemical and physical properties of spent garnet and the effect on strength and bonding of concrete with steel when spent garnet is used as sand replacement. Furthermore, study the behaviour of concrete containing spent garnet when exposed to elevated temperature is necessary because aggregates represent a considerable proportion of volume in concrete, about 70%, and are expected to have an influence on the effect of concrete when exposed to fire (Hager *et al.*, 2016). Such increase in the utilization of spent garnet will reduce the effects of environmental problems and can provide eco-friendly sustainable concrete. This study was used a spent garnet, a by-product of surface treatment operations, as a sand replacement in concrete. Even though the use of waste materials as a sand replacement using spent garnet has been studied by many previous researches, the use of spent garnet in high strength concrete can be considered as a new knowledge to research world. Thus, the focus of this study is more on the effect of mechanical properties of spent garnet concrete at ambient and elevated temperature. Using spent garnet as fine aggregates replacement in concrete mixture could improve the mechanical properties and durability of concrete at elevated temperature.

1.2 Problem Statement

In the past few decades, the high demand for aggregates in the production of concrete is increasing in Malaysia due to rapid growth of construction sector. In 2010, the total usage of natural aggregates in Malaysia was 2.76 billion metric tons, of which 1.17 billion metric tons was sand and gravel (Shettima, 2017). Sand as fine aggregates in concrete is usually produced from mining riverbank and quarries. The digging of sand from the riverbed in excess quantity will affect the environment which includes reduction of water quality and destabilization of the stream bed and banks. Due to global warming and environmental devastation that have become manifestly harmful in recent years, there is a need to find an alternative replacement for river sand as fine aggregate in concrete by the use of industrial waste in the making of concrete.

Over a period of time, different research works had been conducted with the utilization of waste materials from industrial waste as fine aggregates in concrete production. In 2013, the amount of garnet imported from Australia to Malaysia by Malaysian Marine Heavy Industry (MMHE) was 2000 tons for the use of work sandblasting ship. Meanwhile, the total world industrial garnet production was estimated to be 440,000 tons (Gorrill and Lindsay, 2003). Thus, the excessive amounts of spent garnet filled up the space of landfill, in addition to disposal in oceans and rivers. This excessive spent garnet has presented an attractive opportunity to use this waste in concrete mix, thus solving the space for landfill, minimizing the used of river sand and improving the performance of concrete. Spent garnet materials which were used for fine aggregates material among others played significant roles such as behaviour of concrete at elevated temperature. Thus, as the formation of spent garnet was formed at higher temperature up to 400ºC based on Caddick and Kohn, (2013), spent garnet was expected will give better performance as fine aggregates in concrete compared to river sand at elevated temperature.

Generally, reinforced concrete has proven to be a successful material in conditions of both structural performance and strength. Achieving good durability in reinforced concrete is a major ingredient in enabling a social organization to perform its designed use for its anticipated lifetime. Fortunately, exposure to elevated temperature and poor structure can all lead to concrete failure. The fire reaction to reinforced concrete structure will affect the properties of concrete and steel. These include the thermal properties, mechanical properties, deformation properties of materials and material specific characteristics such as spalling in concrete. The spalling effect of concrete can be defined as the breaking up of pieces of concrete when it is exposed to high and rapidly rising temperatures such as those in a real fire. This spalling effect will occur in all types of concrete especially in high strength concrete (HSC) rather than normal concrete (NC) due to its lower thermal stability and lower water-cement ratio compared to NC (Venkatesh, 2014). Figure 1.1 illustrates plaster spalling due to the effect of elevated temperature.

Figure 1.1: View of the laboratory subjected to fire (Iqbal *et al.*, 2017)

The properties of concrete when exposed to elevated temperature are due to its composition and individual components in concrete. Aggregates occupied the high volume of concrete and therefore, behaviour of concrete at elevated temperature was strongly affected by aggregates used in concrete. Generally, aggregates were found to be stable up to 300ºC to 350ºC; however, exposure to higher temperature will affect the properties of aggregates, thermal expansion, conductivity and chemical stability of aggregates (Tufail *et al.*, 2017). Study focused on replacing river sand with spent garnet in a concrete, and the response to elevated temperature, is necessary as the behaviour of concrete at elevated temperature was strongly affected by the type of aggregates. This research is different from previous works which are concerned with the mechanical properties of geopolymer concrete containing spent garnet, as this study is focused on mechanical properties of High Strength Spent Garnet Concrete (HSSGC) and its potential use in terms of structural design at elevated temperature.

1.3 Aims and Objectives

The aim of this study is to investigate the performance of spent garnet as sand replacement in concrete mix and also to determine the effect of concrete when exposed to elevated temperature. The main objectives are as follows:

i. To establish the characterization of spent garnet in terms of physical and chemical properties.

ii. To study the mechanical properties of High Strength Spent Garnet Concrete (HSSGC).

iii. To examine the bonding effect between steel and concrete for High Strength Spent Garnet Concrete (HSSGC).

iv. To investigate the effect of different cover thickness for High Strength Spent Garnet Concrete (HSSGC) when exposed to elevated temperature.

1.4 Scope of the Research

All testing procedures were followed the Malaysian Standard (MS), British Standard (BS), Eurocode Standard (BS-EN), American Society for Testing and Materials (ASTM), and some of the procedures were proposed by previous researchers. The study also would be focused on the use of spent garnet as a waste material in high strength concrete as a sand replacement. The use of spent garnet in this study as sand replacement ranges from 0%, 20%, 40%, 60%, 80% and 100%. The designed (mix) strength of concrete is 60 N/mm^2 at 28 days while the maximum particle size of spent garnet used is 2.36 mm.

For modulus of elasticity, scanning electron microscopy (SEM), pull-out test and elevated temperature, there were only two different types of concrete were tested which are high strength concrete (HSC) and optimum percentage of high strength spent garnet concrete that was determined based on mechanical properties test such as compressive strength, flexural strength and splitting tensile strength.

1.5 Limitation of the Research

Spent garnet in this study was used directly without any treatment. The elevated temperature test in this study is by using an electrical furnace and temperature ranging from 200ºC, 400ºC, 600ºC and 800ºC with one-hour duration. The temperature ranges and duration was chosen as stated above due to suggested by previous research as that certain temperature will shows different results for physical and mechanical behaviour of concrete at one hour duration. The cooling effect during fire test was not considered in this study. The change of colour, cracking, residual compressive strength, ultrasonic-pulse velocity, weight loss of concrete and tensile strength of steel under elevated temperature were included in this study.

1.6 Significance of the Research

Apparently, the use of spent garnet can reduce the consumption of river sand and significantly enrich the properties of concrete at ambient and elevated temperature. The use of high volume of spent garnet will help reduce the environmental pollution. Besides that, high strength concrete (HSC) was expected to be better than normal concrete (NC) in terms of residual compressive strength when exposed to elevated temperature in the range of 28ºC to 400ºC. However, the only major problem for HSC at higher temperature at above 600ºC was spalling effect. By taking into consideration spent garnet as a waste produced from sandblasting work, the use of spent garnet in concrete is strongly encouraged as it will reduce the space for landfill and is environmental friendly. It is hoped that the use of a higher volume of spent garnet in this study compared to previous research will help to reduce the usage of river sand and balance the ecosystem. Besides that, studying the behaviour of different fine aggregates (sand and spent garnet) at elevated temperature and bonding effect with steel can be of assistance in evaluating the performance of spent garnet as sand replacement as structural design for fire safety and its performance in terms of strength and durability.

1.7 Thesis Organization

There are six chapters in this thesis in order to achieve four objectives of the research. The arrangement of thesis is shown below:

I. Chapter 1: Description on the background problem. This chapter were also provided information on aims and objectives, scope and limitation, and significance of the study.

II. Chapter 2: Explains the properties of garnet and the use of spent garnet in concrete from previous researcher. This chapter also provide a review of the use of other materials as sand replacement, describe the behaviour of concrete and steel when exposed to elevated temperature, discuss the influences of concrete cover or spacers as a protection for reinforcement during fire taking place and in terms of bonding effect with steel.

III. Chapter 3: This chapter were described the experimental program including methodology, casting and testing of various types of specimens.

IV. Chapter 4: This chapter presents the test results and discussion obtained from the physical and chemical properties of spent garnet. Moreover, aspects of mechanical properties also were presented in this chapter.

V. Chapter 5: Aspects of performance of High Strength Concrete (HSC) and High Strength Spent Garnet Concrete (HSSGC) when exposed to elevated temperature were discussed in this chapter.

VI. Chapter 6: This last chapter concludes this study by stating the findings and contribution of the research to the existing knowledge. Furthermore, recommendations are also provided for further research in this area.

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