EFFECT OF QUARRY DUST INCORPORATION OF TERNARY CEMENT REPLACEMENT

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ABSTRACT

This study explored the possibility of using quarry dust as a replacement for natural river sand in concrete production. The behaviors of individual materials such as quarry dust (QD), ground granulated blast-furnace slag (GGBS), pulverized fly ash (PFA) and silica fume (SF) were determined. Laboratory investigations were also conducted to evaluate the characterization of quarry dust and by-products materials in terms of microstructure, physical and chemical properties. Furthermore, mix design and the evaluation of the fresh and hardened properties of the ternary blend concrete were executed. Series of concrete were prepared with ternary blend proportion of OPC with sand (control), QD, GGBS, PFA and SF using water to cement ratio (w/c) of 0.30 and 0.20. Fresh properties of mixtures in terms of concrete slumps and density were studied. The hardened properties were examined based on mechanical strengths, deformation characteristics, durability properties and corrosion measurement. Finally, microstructural tests in terms of X-ray diffraction (XRD) and field emission scanning microscopy (FESEM), were concurrently conducted on control and ternary blended concrete to determine the interaction and effect of the ternary material that brings about the performance of the concrete. Results showed that QD and by-products materials affect mixture workability negatively. The inclusion of super plasticizer showed tremendous influence in increasing the workability and reduced this drawback. Blended concrete mixes at various replacement of GGBS, PFA and SF with quarry dust takes longer time to set within 3 to 4 hours whereas control mix is the fastest to set at an hour. Quarry dust blended with concrete indicates that the compressive strength gained between 5.3% to 7.3% compared to control concrete. Furthermore, the constituents of ternary blended it has the quality to be used as partial replacement cement.

ABSTRAK

Kajian ini meneroka kemungkinan penggunaan debu kuari sebagai pengganti penggunaan pasir sungai ke dalam bancuhan pengeluaran konkrit. Pemerhatian terperinci dilakukan keatas tindakbalas bahan-bahan seperti debu kuari (QD), tahi besi (GGBS), abu (PFA) dan silika (SF). Penyelidikan serta ujikaji dalam makmal juga turut dilakukan untuk menilai ciri-ciri debu kuari dan bahan-bahan sampingan dari segi struktur mikro, sifat fizikal dan tindakbalas kimia. Penilaian kekuatan terhadap campuran konrit dilaksanakan dalam keadaan sebelum dan selepas konrit menggeras. Keseluruhan pengunaan campuran konkrit termasuk campuran konkrit kawalan dengan QD, GGBS, PFA dan SF adalah pada kadar nisbah air-simen dari 0.30 dan 0.20. Sifat kemerosotan, ketumpatan, kekuatan mekanikal, ciri-ciri perubahan bentuk, kekuatan dan mampatan serta kelenturan campuran konkrit telah dijalankan ujian dan kajian terperinci. Selain itu, ujian mikrostruktur dari segi X-ray diffactions (XRD) dan field emission scanning microscopy (FESEM), dilakukan secara menyeluruh pada campuran konkrit untuk menentukan interaksi serta kesan sampingan bahan-bahan yang telah dikoperasikan dalam campuran konkrit tersebut. Hasil kajian menunjukkan bahawa penggunaan bahan QD dan produk sampingan telah mempengaruhi kebolehkerjaan campuran secara negatif. Penggunaan super plasticizer telah menunjukkan pengaruh luar biasa yang dapat mengatasi kekurangan dengan peningkatan kebolehkerjaan campuran konkrit. Campuran konkrit dengan kepelbagaian penggantian GGBS, PFA dan SF dengan debu kuari memerlukan kadar masa sekurang-kurangnya dalam sejam sehingga mencapai ke 4 jam untuk mengeras. Penggunaan debu kuari dalam campuran konkrit memperlihatkan pencapaian peningkatan kekuatan mampatan diantara 5.3% sehingga 7.3% berbanding dengan konkrit kawalan. Tambahan pula, unsur-unsur campuran konkrit ini telah membuktikan mempunyai kualiti yang memberansangkan serta setanding untuk digunakan sebagai simen penggantian separa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standards
DOE	-	Department of Environment
FESEM	-	Field Emission Scanning Electron Microscope
GGBS	-	Ground Granulated Blast Furnace Slag
LOI	-	Loss on Ignition
OPC	-	Ordinary Portland Cement
PFA	-	Pulverized Fuel Ash
POFA	-	Palm Oil Fuel Ash
QD	-	Quarry Dust
RHA	-	Risk Husk Ash
RCPT	-	Rapid Chloride Penetration Test
SF	-	Silica Fumes
SP	-	Superplasticizer
UPV	-	Ultrasonic Pulse Velocity

LIST OF SYMBOLS

Al_2O_3	-	Aluminium Oxide
b	-	Average Width of Specimen, m
d	-	Average Depth of the Specimen, m
CH	-	Calcium Hydrate
Ca $(OH)_2$	-	Calcium Hydroxide
CaO	-	Calcium Oxide
(C-S-H)	-	Calcium Silicate Hydrate
D	-	Diameter of the Specimen (mm)
C_2S	-	Dicalcium Silicate
Fe_2O_3	-	Ferric Oxide
R	-	Flexural Strength
MgO	-	Magnesium Oxide
ρ	-	Mass Density
P	-	Maximum Applied Load, N
MPa	-	Mega Pascal
L	-	Span Length, mm
SiO_2	-	Silicon Dioxide
Fct	-	Tensile Splitting Strength (N/mm^2)
C_4AF	-	Tetracalcium Alumino Ferrite
C_3A	-	Tricalcium Aluminate
F	-	Ultimate Load at Failure (N)
ν	-	Velocity
π	-	Pi, 3.14

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Construction industry continuously ascend tremendously to meet the needs and desires of market trend in conjunction with the advancement of concrete technology. The latest concrete technology is important to produce higher quality of concrete which tends to beneficial source to mankind, resulting in a more economical, durable, sustainable, and stronger structure. Fundamentally, concrete regards as the most popular building materials with excellent demand in market that highly targeted in the eyes of the world especially the construction industries. This industry has foreseen to get better with the new green buildings technologies enhancement introduced with better methodology and ways to construct throughout the world globalization. One of the major challenges that spell out is to introduce and create more ideas of ways and methodology of improvement for getting the best substitution of natural resources and at the same time protecting the environment. Throughout the construction industry sector, which includes concrete industry, the estimated cost of environmental compliance is predicted to be high as reported in the Federation of Malaysian Manufacturers (FMM).

Other challenges will be on the continual used of the substitution materials, creating more awareness on its contributions to the serious environmental problems that the world is currently facing. The irresponsible parties that continuing using natural resources in their production ignoring the circumstances of getting the sources to be exhausted will led to irremediable deterioration of world asset. Therefore, it is important to get the alternatives activities such as quarrying of fine aggregates or other recycled aggregates materials from the quarry production. The consumption of natural aggregate concrete as the largest component material is a key

concern because it comprises 70% to 80% of the total volume (Neville, 2011). More than 10 billion tonnes of concrete were produced annually worldwide (Yaprak et al., 2011). The high demand of aggregate to produce concrete requires massive use of natural aggregate which will destroy the ecological balance of the environment. These include depletion of virgin aggregate deposits. Sand is generally used as fine aggregate in concrete and usually produced from mining exploration. Sand mining is of great importance to the Malaysian economy. It should, however, be recognised that the processes of prospecting, extracting, and transporting have great potential for disrupting the natural environment (Rabie et al., 1994). Physical impacts of sand mining include reduction of water quality and destabilization of the stream bed and banks. Sand mining can also disrupt sediment supply and channel form, which can result in a deepening of the channel as well as sedimentation of habitats downstream. Channel instability and sedimentation from instream mining also can damage public infrastructure (bridges, pipelines, and utility lines). This process can also destroy riverine vegetation, cause erosion, pollute water sources and reduce the diversity of animals supported by these woodlands' habitats (Byrnes et al., 1995).

In view of that, there is urgent need to find alternative replacements for river sand as fine aggregate in concrete by exploring the use of industrial waste in the making of concrete. The challenge for the civil engineering community with the concept of sustainable development involves the use of waste materials and by-products at reasonable cost with the lowest possible environmental impact. The entrenchment of sustainable environment has become very important to preserve valued environmental conditions as well as available resources. As part of measures toward fostering sustainability, the reduction in emissions of greenhouse gasses, the depletion of fossil fuel and waste generation and disposal has become critical issues for consideration. The construction industry through its activities has strong impact on the environment. Although these impacts are both positive and negative, the latter gives an underlying motive for the concern to seek mitigations for environmental problems. Currently, achieving a sustainable environment and eco-friendly community through effective recycling of waste materials in the construction industries are the fundamental issues worldwide. The utilization of certain categories of waste products of industries in construction and as building materials to produce concrete seems to provide adequate solutions to these issues. Various research has

broadly proven that waste materials from industries such as quarry sand, ground granulated blast furnace slag, recycled concrete, fly ash, and ceramic waste can be utilized in the production of sustainable concretes. However, the increasing number of industrial wastes being produced due to the rapid increase in industrialization worldwide has dwindled the space for landfill. This problem of landfill and other economic and environmental issues clamour for more usage of industrial waste materials through extensive research and utilization in concrete to produce green and eco-friendly environment. Naik et al. (2003) had performed an investigation using industrial wastes/by-products such as quarry dust (QD), pulverized fly ash (PFA), ground granulated blast furnace slag (GGBS) and silica fumes (SF) which proven positive results on the strength gained in concrete and cost savings, thus support the use of environmentally friendly materials. To find solution to the environmental issues raised, there is need to further study and come up with sustainable utilization of the wastes/by-products generated. Huang et al. (2013) and Zhao et al. (2014) stated that the current utilization of wastes/by-products at 7% to 10% is very low compared to huge disposal ranging from 5 to 7 billion tonnes per year worldwide as agreed by (Edraki et al., 2014). Besides, quarry dust is the final product of aggregates production, regards as one of the wastes/by-products which are potential to replace regular used of natural sand as a fine aggregate in concretes. Siddique et al. (2009) investigated such types of materials which can be substituted partly/fully for natural sand (fine aggregates) in concrete mixtures without sacrificing the strength and durability.

To increase wastes/by-products utilization, extensive research on strength and microstructure that will provide better understanding of long-term effect is needed. Such increase in the utilization of wastes/by-products will reduce the effects of environmental issues and loss of life of human and aquatic animals. This research evaluating the performance of concrete made by replacing cement with the utilization of fly ash (PFA), ground granulated blast furnace slag (GGBS) and silica fumes (SF). This research will be employed quarry dust as replacement to natural sand. This will provide eco-friendly, economic, and environmentally sustainable mining industries and provide alternative to sand mining for cheaper concrete and construction materials. A few researchers such as Celik et al. (1996); Sahu et al. (2003); Tripathy et al. (2006); Shi-Cong et al. (2009); and Kiran-Kumar et al. (2016) had reported the

use of quarry dust (QD) as partial replacement of fine aggregate. They have been highlighted that increasing the dust percentage up to 10% improved the compressive strength and flexural strength of the concrete. Sahu et al. (2003) stated there is a remarkable increase in compressive strength, modulus of rupture and tensile splitting strength when sand was partially replaced by quarry dust up to 40% in concrete.

1.2 Statement of the Problem

In the past few decades, the demand for construction natural sand is increasing in Malaysia due to rapid economic development and subsequent growth of building activities. Thus, in many of the occasions has resulted indiscriminate mining of sand from instream and floodplain areas leading to severe damages to the river basin environment. During the year 2010, Malaysia consumed 2.76 billion metric tons of natural aggregate, out of which 1.17 billion metric tons, or 42.4%, was sand and gravel. The percentage of total aggregate production that is sand and gravel varies widely from state to state. Melaka consumes 7.7% sand and gravel, which is lower than any other state. Selangor, Johor, Terengganu, and Federal territory (Kuala Lumpur and Putrajaya) all consume 100% sand and gravel (Ashraf et al., 2011). Sand mining has environmental issues, which include depletion of virgin deposits, destruction of landscape, reduction of farm and grazing land, collapsing of riverbanks, deforestation, and water pollution (Ako et al., 2014).

During the critical stage of sand shortage in year 2017, the Star newspaper had reported that Selangor and Federal Territory (Kuala Lumpur) were facing a serious sand shortage that can disrupt the construction and manufacturers sectors. The critical situation has forced the state of Selangor importing the natural sand sources from Perak largest sand exporter as shown in Figure 1.1. Besides, Peninsular of Malaysia encounter the sand shortage issues, the Sabah Builders Association (SBA) has received complaints from members that they have been facing sand supply shortage since June 2018, resulting in the price increase over the past months. The remedies for these impacts are the use of waste material as alternatives to river sand (Sreebha et al., 2011).

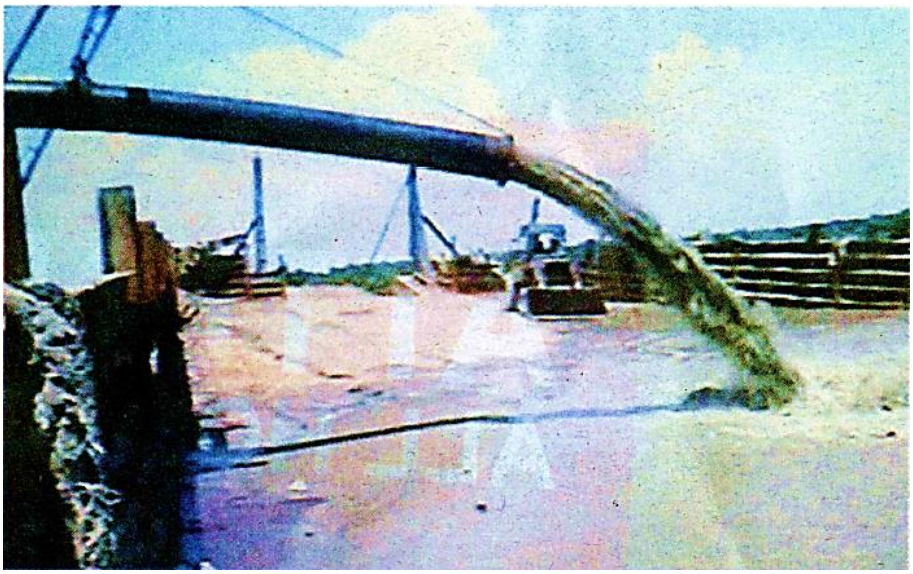

Figure 1.1 Sand Being Extracted Along Sungai Perak Near Teluk Intan and Exported Out to Selangor (The Star Newspaper Article)

Meanwhile, the worldwide is urging for the conservation of natural raw materials due to increasing demands of construction industry fueled the intense global research towards economic utilization of the waste to produce eco-friendly construction materials for durable and sustainable concrete structures. Over the period, various research works were conducted to engage the use of waste materials from industrial wastes/by-products as fine aggregate in concrete structure. Pozzolanic materials such as pulverized fly ash, ground granulated blast furnace slag and silica fumes as ternary blend of cement which were used as partial cement replacement also played significant roles. Various researchers agitate for durability test for concrete that utilizing pozzolanic materials especially ground granulated blast furnace. Ugama et al. (2014) suggested that more test, varying water-cement ratio and mix design of concrete with quarry dust and ternary cement blend should be investigated. Kuranchie et al. (2015) reported that the ferrous content in iron ore has significant negative effect on the corrosion which might have long term effects on durability of concrete. Corrosion of concrete has an important effect on the durability performance of concrete (Guneyisi et al., 2013). Moreover, to satisfy the future demand and desire needs, this further research on the effects of quarry dust incorporation of ternary blended cement in concrete is required for avoidance of the depletion of natural resources to maintain an ecological balance.

1.3 Objectives of the Study

The main aim of this research is to use quarry dust as a substitute to sand replacement incorporates ternary blended cement in concrete with the following objectives:

(a) To analyze quarry dust, fly ash, ground granulated blast furnace and silica fume (physical, mechanical, and chemical) properties according to standard requirements for sand (ASTM, BS or EC2).
(b) To determine the effects of quarry dust on the properties of fresh and hardened ternary blended concrete in term on strength performance and workability.
(c) To evaluate the effect of quarry dust on ternary blended concrete material composition and microstructural properties.
(d) To study the comparison between ternary blended concrete made by quarry dust and sand as fine aggregates with control specimen.

1.4 Research Questions

This research seeks to address the following questions:

(a) Is quarry dust, fly ash, and ground granulated blast furnace slag and silica fumes physical, mechanical, and chemical properties are within the requirements of relevant (ASTM, BS or EC2) codes and standards?
(b) Will quarry dust contribute to improving strength and other properties of ternary blended concrete?
(c) Will quarry dust causes any negative effect on the concrete structure?
(d) Will there be any significance differences when utilizing quarry dust as fine aggregates?

1.5 Scope of the Study

The scope of work covers the mechanical and physical properties and mainly focused on the development of concrete containing quarry dust as replacement of river sand incorporates with ternary blended cements, which include Portland cement, fly ash and ground granulated blast furnace slag or silica fume. High strength ternary blended concrete mixtures of grade 100 MPa at 0.20 water/cement ratios were designed. Concrete mixes were designed accordingly to the application of the Department of Environment (DOE, 1992) referring (ASTM C94, 1986; BS 146, 2002; BS 4246, 1996). The properties of the constituent concrete mixtures behavior and microstructural characteristics were examined.

The evaluation of workability, strength properties, physical and mechanical properties of hardened concrete were also investigated. This includes the slump, setting time, density, compressive, tensile strengths, flexural strengths, and ultrasonic pulse velocity (UPV). Fresh concrete properties are determined by conducting the slump test accordance to BS EN 12350-2 (2019) whereas the stiff, initial, and final set of concrete to be carried out referring MS 30 (1992). The mechanical properties of harden concrete are determined by conducting density test accordance to BS EN 12390-7 (2019), ultrasonic pulse velocity (UPV) to be carried out complying BS EN 12504-4 (2004) on every sample inclusive of cubes, prism and cylinder before compressive, tensile, and flexural strength tested. The compressive strength tested cubes compliance with ASTM C31 (2019) with specification of (150x150x150) mm. The sample size of (100x100x500) mm were used on the flexural strength test with accordance to BS EN 12390-5 (2019). Tensile splitting strength to be carried out with cylinder size of (100 in diameter x 200 long) mm complying with (ASTM C39, 2021; BS EN 12390-6, 2009). Samples to be casted and tested at the age of 4 days, 7 days, 14 days, 28 days and up to 56 days after the wet curing process at the curing tank. In addition, control specimen and ternary blended concrete were compared in terms of workability and strengths.

The ternary bended concrete mixture was used to study the microstructure test in terms of Field Emission Scanning Electron Microscopic (FESEM) and X-ray Diffraction analysis (XRD) of hardened concrete. A comprehensive microstructural assessment was also performed to examine the microstructure morphology on the concrete mixes. X-ray diffraction analysis was used to study the characterization of crystalline materials between fly ash, ground granulated blast furnace slag, silica fumes and OPC.

1.6 Significance of the Research

In concrete production, cement, and fine aggregates (gravel and sand) are both the main important constituent ingredient used. According to the report in Federation of Malaysia Manufacturers (2015), overused of natural resource in the world has caused these resources led to a serious impact of wearing down and contributes to environmental matters. In addition, the flora and fauna eco-system was disrupted thus forcing them to the danger zone. Environmental-friendly, energy efficient and cost effective with alternative materials produced from utilization of wastes/by-products will encourage the market potential to fulfil concrete producers and builders needs in rural and urban areas. Generally, the use of wastes/by-products such as quarry dust, fly ash, ground granulated blast furnace slag and silica fumes like other recycling effort limits wastes disposal (Lottermoser, 2011). At present, these wastes are disposed as landfill materials without any economic benefit in return and considerable amount of money is needed for acquiring land for disposal.

The utilization of wastes/by-products has become an attractive alternative in construction industry. Thus, using quarry dust for concrete as a replacement for fine aggregate will slow the consumption of natural resources, encourage innovation and local industries, create jobs, and teach responsibility for the environment shared by all (Ilangovana, 2008). Whereas the utilization of pozzolanic materials such as fly ash, ground granulated blast furnace slag and silica fumes will help to reduce the emission of carbo dioxide thus preventing from global warming. Finally, when the technology of concrete incorporating quarry dust is articulated, it will reduce the cost

and consumption of natural sand and overall construction cost, thus producing green concrete and make construction affordable (Safiuddin et al., 2000b). Many of the researchers have proven to obtained good results during the application of addition wastes/by-products materials in concrete and has been supported in many previous research studies. However, none in Peninsular of Malaysia yet to incorporates ternary cement blend with quarry dust as sand replacement in such high strength of concrete grade 100 MPa. Therefore, with the application of all the addition wastes/by-products, the optimum results in strength will be predicted ascending positively.

1.7 Thesis Outline

To achieve the objectives of the study, the laboratory experiments and trial run have been carried out in this research. This thesis is classified into five different chapters. The thesis outline is as follows:

Chapter 1: This chapter give a brief description of the study background, statement of the problem, objectives of the study, research questions, scope, and significance of the study.

Chapter 2: Review of the available, relevant, and related literatures.

Chapter 3: The chapter focuses on the breakdown of the experiments for this research involving methodology for characterization of materials used and the procedures for the tests of fresh and hardened properties; and microstructure properties of ternary blended concrete.

Chapter 4: The chapter analyses and discusses the results of physio-chemical properties of quarry dust, fly ash, ground granulated blast furnace slag, silica fumes and the effect of quarry dust on fresh ternary blended concrete properties. The chapter also discusses the results obtained on workability and hardened properties in terms of slump, setting time, density, compressive, flexural, tensile strength, and ultrasonic pulse velocity (UPV). This chapter reports the results and discussions

arising from the various strengths tests conducted on control specimen and ternary blended concrete. Field Emission Scanning Electron Microscope (FESEM) and X-ray Diffraction analysis (XRD) results are analyzed and discussed in this chapter. The microstructure studies were examined at 7 and 28 days of concrete strength development.

Chapter 5: This chapter deals with the overall conclusions drawn from the research outputs and lists of recommendations based on the research findings for future researchers in this field of study for further improvement.

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LIST OF PUBLICATIONS

Non-Indexed Journal

1. **Jaharatul.,** Ali. N, Mohamed. R and Mua'zu M. A. (2018). The Effect of Quarry Dust with Cement By-Products on Properties of Concrete. *Malaysian Journal of Civil Engineering*, 30(3), 398-411. https://doi.org/10.11113/mjce.v30.16067

Non-Indexed Journal Conference Proceedings

1. **Jaharatul.,** Ali. N, Mohamed. R and Mu'azu M. A. (2016). The Effect of By-Products Partial Replacement Trial Mix on Concrete Strength and Performance. *Proceeding of 7th International Conference on Postgraduate Education*, iCPE-07.