ENVIRONMENTAL SUSTAINABILITY AND ENGINEERING PERFORMANCE OF OPC-FLY ASH MORTAR MIXES WITH DIFFERENT WORKABILITY

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ABSTRACT

Engineering performance and environmental sustainability of mortar mixes through the incorporation of different replacement levels of fly ash at 10%, 20%, 40% and 60% respectively were investigated. Samples of mortar were prepared by using four different water / binder ratios of 0.35, 0.40, 0.45 and 0.50, and were also prepared with different dosages of superplasticizer to give three ranges of workability that is normal, high and self-compacting spread flow. Engineering performance was assessed through compressive strength at 3, 7, 14, 28 and 90 days and the durability aspect through the water absorption test when mortar reached 28 days of age. Environmental performance or basically the sustainability aspect was assessed through the determination of CO_2 footprint which denotes the environmental impact of each mix. The relationship that is to be investigated lies in the potential of CO_2 reduction in the mortar mixes, when cement was replaced by fly ash. Analysis of relative performance index for engineering performances and environmental sustainability found that regardless of the w/b ratios, for every type of flow, 60% replacement of fly ash gave the lowest relative performance index with an average of 50% less than OPC mortar. Cost analysis revealed that, cost per kg of mortar for self-compacting flow increased by 44% compared to normal flow. Optimum mix analysis found that with replacement of 10% to 20% of fly ash, gave a balance in environmental sustainability performance and engineering performance

ABSTRAK

Tahap prestasi kejuruteraan dan kemampanan alam sekitar bagi campuran simen mortar melalui penggantian abu terbang yang mempunyai peratusan berbeza 10%, 20%, 40% dan 60% masing-masingbdikaji. Sampel mortar disediakan dengan menggunakan empat air / pengikat nisbah yang berbeza 0.35 , 0.40 , 0.45 dan 0.50, dan juga disediakan dengan dos bahan tambah yang berbeza untuk memberi tiga julat kebolehkerjaan iaitu normal , tinggi dan simen mortar terpadat sendiri . Prestasi Kejuruteraan telah dinilai melalui kekuatan mampatan pada 3, 7, 14 , 28 dan 90 hari dan aspek ketahanan melalui ujian penyerapan air apabila mortar mencapai usia 28 hari. Prestasi alam sekitar atau pada dasarnya aspek kemampanan telah dinilai melalui penentuan tahap CO_2 sebagai tanda aras kesan alam sekitar bagi setiap campuran. Hubungan terhadap potensi pengurangan tahap CO_2 dalam mortar campuran adalah aspek yang dilihat, apabila kandungan simen digantikan dengan abu terbang. Analisis terhadap indeks prestasi relatif bagi prestasi kejuruteraan dan kemampanan alam sekitar menunjukkan tanpa mengira nisbah air/pengikat, untuk setiap jenis campuran 60% abu terbang menunjukkan tahap indeks prestasi yang rendah dengan purata 50% daripada simen mortar biasa. Analisis kos pula mendapati kos bagi setiap kg mortar terpadat sendiri adalah lebih tinggi sebanyak 44% jika dibandingkan dengan aliran normal. Analisis bagi menentukan campuran optimum mendapati bahawa penggantian abu terbang sebanyak 10% ke 20% memberikan penggantian yang paling optimum kerana dapat membantu dalam kesimbangan kemampanan alam sekitar dan juga pretasi kejuruteraan.

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LIST OF SYMBOLS AND ABBREVIATIONS

CO_2	Carbon dioxide
GHG	Green house gases
SCC	Self-compacting concrete
SCM	Self-compacting mortar
SP	Superplasticizer
FA	Fly ash
µm	Micrometer
GGBFS	Ground granulated blast furnace slag
OPC	Ordinary Portland cement
MPa	Mega Pascal
N_2O	Nitrous Oxide
CH_4	Methane
PFC	Perfluorocarbons
HFC	Hydrofluorocarbons
SF_6	Sulphur hexafluoride
GWP	Global warming potential
CO_2-e	Carbon Dioxide Equivalent
SAP	Standard Assessment Procedure
WBCSD	World Business Council for Sustainable Development

LIST OF SYMBOLS AND ABBREVIATIONS

CKD	Cement kiln dust
$CaCO_3$	Calcium carbonate (Limestone)
SiO_4	Quartz
$CaSO_4$	Calcium sulphate (Gypsum)
NaCl	Sodium chloride
K_2SO_4	Arcanite
$2(C_2S)\cdot CaCO_3$	Spurite
$2(C_2S)\cdot CaSO_4$	Sulphospurite
CaO	Calcium oxide (Lime)
$Ca\,(OH)_2$	Calcium hydroxide (Free Lime)
H_2O	Hydroxide
TNT	trinitrotoluene
ANFO	Ammonium nitrate and fuel oil
AA	Alkali-activated
XRF	X-ray fluorescence

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Sustainability has become a central issue in the construction industry nowadays. Sustainable construction implementation and the effort to create green buildings has become a significant subject in Malaysia in current years and have been addressed under the Malaysian Construction Industry Master Plan (2005 – 2015). As a productive sector, the construction industry constantly contributes significantly to the Malaysian economy. Current statistics depicts that construction industries growth recorded 5.3% in 2007 and this value put in 2.1% of the total Gross Domestic Product (GDP) of Malaysia (Kamar & Hamid, 2011). These have led to the enforcement of law by the Ministry Of Energy, Green Technology and Water for the construction players in meeting sustainable requirements for their construction projects. These include the utilization of green materials, the provision of safe environment, and the utilization of non-toxic or non-hazardous materials during pre- and post- construction activities. Based to the Kyoto Protocol 1997, The United Nations Climate Change conference in Bali 2007, G8 Summit in Italy 2009, and Copenhagen Commitment 2009, with the objective to assist in combating the climate change many developed countries targeting for realistic greenhouse gas (GHG) emission reduction (Ng, Chen, & Wong, 2013). Signed in 1997, the Kyoto protocol aim for decreasing the greenhouse gas emissions in developed countries by 5.2% from the 1990 level by 2008–2012. With respect to Kyoto protocol goals, in order to reduce its CO_2 emissions, cement industry has been optimistic maintaining and developing its manufacturing process. The European Union commenced the Emissions Trading Directive in 2003, in order to practise the Kyoto target, plant-specific CO_2 caps establish into the major power manufacturing and energy intensive industry sectors (e.g. cement, oil refining, steel, pulp, and paper) (Europian Union, 2003). Significant cost impact will occur if the cement industries fail in meeting the quotas, hence they are strongly encouraged to follow the protocol.

Cement plays a vital task in terms of financial and public significance since its principal rests in building and improving infrastructure facilities. Concrete and mortars, a cement based material are utilize in particularly bulk quantity. World population growth and the urban development in many countries will definitely warrant the utilization of cement and cement-based materials. For instance, concrete production was recorded for more than 10 billion tons back in 2009. It is also crucial to note that this industry also generates heavy pollutants. A total of 4% global warming origins from human activities were released from cement production which accounted for 5-6%. These leads to release large amounts of organic pollutants, including dioxins and heavy metals also particles (Rodrigues & Joekes, 2010). It was reported that without any changes in technology and scientific method, 50% CO_2 will simply released by the production of cement industry (Lund, 2007).

Sustainability is mainly governed by three main pillars namely economy, social and environmental. Economy is a contributor to sustainability, where the utilization of any green material will help provide low economic impact and in addition will boost Malaysia's gross profit. Through the utilization of waste materials, this will somehow help mitigate the hazard to the community and improve the social life of the community itself since safer environment is able to be created. The environment is the main factor contributing to sustainable issues, since we are nowadays troubled by the ozone depletion which is harmful to our atmosphere. Large amount of greenhouse gases released may cause the depletion of ozone. The clinker production in cement manufacturing is established for quite some time as a main contributor of CO_2 emission worldwide. Attempts to reduce CO_2 emission in concrete include reducing the clinker content in the cement production since one tonne of carbon dioxide (CO_2) tends to be produced during the production of one tonne clinker (Fantilli & Chiaia, 2013); this means that the CO_2 emission in concrete mixes is reduced by minimizing the cement content. In order to do this, a constituent material or supplementary cementing materials or preferably fly ash is required to replace and reduce the cement content. CO_2 which is emitted during the production of concrete can be measured by examining the CO_2 footprint of the concrete.

Fly ash is products that originate from the ignition of pulverized coal from thermal power plants. The system so called as powder-collection eliminates the fly ash, as a fine particulate residue, from the combustion gases before they are released into the atmosphere. Fly ash which is categorized as a fine waste material is the most consumed mineral additive added to concrete mix production worldwide. (Malhotra and Ramezanianpour, 1994) maintain that inclusion of fly ash in concrete, may affects most aspects of concrete since it acts both as fine aggregate or a cementitious component. Fly ash affects the rheological properties in fresh state and strength, porosity and durability during the hardened state. In spite of that, it helps in saving the cost and energy consumed in the manufacturing of concrete.

In Malaysia, fly ash is categorized as an industrial waste material, where it is normally deposited into landfill. Fly ash is normally discarded to the environment without giving any financial return; normally there is merely environmental pollution observed, together with issues of disposal (Karim, Zain, Jamil, Lai, & Islam, 2011). Billion tons of industrial wastes are generated annually and the amount of land-filled wastes are radically increased in consequence of industrial development and urbanization (Zhang, Gao, Gao, Wei, & Yu, 2013). For instance, production of fly ash in Malaysia is believed approaching over 2 million tons annually and anticipated to double-up in 2013 since the stipulation for energy is increased fast (RockTron International, 2010). The increased production of fly-ash from thermal plants causes the quantities of fly-ash deposited into landfills to double. Thus, less consumption in the industrial waste materials will result in the disposal landfill space being occupied by time. Furthermore, the occupied space in landfills nowadays has become environmental problems worldwide. This issues become even worse since it is reported by (Izquierdo & Querol, 2012) that leachate of fly ash deposited into the landfill produces traceable elements that may harm the environment and consequently leading to the social community being exposed to hazard .

Mortar has been extensively used as binder and in rectification of structural works. Conventional-type mortar using the combination of sand, cement and water has been used since decades. As mortar serves as the basis for the workability properties of self-compacting concrete (scc), these properties could be assessed by self-compacting mortars (scm) which serve .As an integral part of designing self-compacting concrete, self-compacting mortar acts as basis for the workability properties (Şahmaran, Christianto, & Yaman, 2006).

Engineering properties is the common measure for determining the characteristics and nature of any materials. Engineering properties can be categorized into two states which are the fresh state behaviour and hardened state behaviour. Fresh state is determined as the materials are in raw condition or mixed in dry or wet condition. Fresh state measurement in mortar mixes includes the slump flow, V-funnel, density, viscosity. Meanwhile, the hardened state is determined as the mixes undergo a hardening process and in a hardened physical state, normally in cube or cylindrical cube. The measurements for the hardened state include the compressive strength, absorption test, shrinkage test and other measurements.

1.1 Background of Problems

High sensitivity to greenhouse issues, global warming and sustainability at present times has become major concern in this research. Environmental issues have become central to economic and political debates these days. Since the cement manufacturing generates the largest percentage of the production of carbon dioxide in the environment and approximately 5% of the world's anthropogenic CO_2 emissions, the use of cement in concrete technology should be minimized. Portland cement is accountable for 74% to 81% of the total CO_2 emission and leading as primary source of CO_2 emission released by concrete producers (Flower & Sanjayan, 2007). Typical approaches to alleviate emissions, solely on the production of cement, will not be capable to compensate the increase by factor of 2.5 for the next 40 years of cement-based products. Further improvements are necessary including raise in the effectiveness of cement use (Damineli, Kemeid, Aguiar, & John, 2010). Using residues from other industrial sectors can also improve the sustainability of cement industry (F. A. Rodrigues, 2011). A major decrease of Portland cement clinker in the concrete will occur by utilizing superplasticizer sufficiently and usage of high reactive cements. Furthermore, optimization of particle-size distribution and lessening the water proportion will provides similar reduction of cement clinker (Proske, Hainer, Rezvani, & Graubner, 2013).

In order to minimize the usage of ordinary Portland cement in concrete technology, waste products such as fly ash powder are used that acts as a substitution of cement in concrete. Sustainable technology is also seen as a key element in serving to diminish greenhouse issue. Environmental sustainability in concrete mixtures was mainly focused on producing "green concrete" by using or replacing part of the mixture with "green products". Recent research that has focused particularly on the environmental sustainability aspect in concrete is done by (Henry, Pardo, Nishimura, & Kato, 2011).

(Becchio, Corgnati, Kindinis, & Pagliolico, 2009) replacing ordinary aggregates with wastes from woodworking activities known as mineralized wood concrete (MWC) as an opportunity for composing additional sustainable lightweight concrete

(Fantilli & Chiaia, 2013) in their research investigate the combination of mechanical behaviour and the environmental aspect. They were targeting of develop an ecological concrete with satisfactory engineering performances, by proposing an index of ecological-mechanical ratios.

Concrete is material that commonly used widely as building material in the world. Producing green concrete is the aim of this research and to implement it, mortar was selected as the main subject. The utilization of waste material is synonymous with the production of green concrete, since waste materials such as fly ash that is deposited into landfills without further consumption, consume a lot more space in landfill than necessary and it will further become environmental problems worldwide. Conventional concrete has become too common when replaced with waste materials, thus new technology in concrete so-called the self-compacting concrete (scc) initially developed in Japan has been adopted in this research. With the aim to produce green concrete by utilizing fly ash, and produce less CO_2 to the environment, environmental sustainability becomes a key criterion in ensuring that the green issues are achieved. Thus, CO_2 footprint is determined and a relationship between environmental sustainability and engineering performances is developed.

1.2 Research Objectives

i. To determine the effect of fly ash for different flowability mortar.

ii. The relationship between engineering properties performance (strength and durability) and environmental sustainability performance (CO_2 footprint)