HIGH STRENGTH GREEN CONCRETE BY USING BIOMASS AGGREGATE

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To my beloved family, lecturers and friends

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ABSTRACT

The use of High Strength Concrete (HSC) for construction, especially for multi-story buildings, has become very common in industrialized and developing countries. But for a variety of reasons, the HSC construction industry is not sustainable because of it consumes huge quantities of natural materials and production of the portland cement, which is a major contributor to greenhouse gas emissions, global warming and climate change. The aim of this research is to identify the performance of HSGC with ingredients of biomass aggregate; fly ash and Supracoat SP800 which are mostly industrial byproducts make the product environmentally friendly. The study was carried out to identify the chemical properties of biomass aggregate, and to determine the engineering properties and optimum mix design of the High Strength Green Concrete (HSGC). A total of 90 cube samples with replacement biomass aggregate (15% & 30%) and fly ash (4%, 6% & 8%) were casted and compressive strength tested at the age of 7, 14 and 28 days after curing in water. The overall results shown that the workability and compressive strength will decrease with the increased of the replacement granite with biomass aggregate. But the workability and compressive strength will increase with the incorporation with the replacement cement by fly ash. The HSGC gained highest compressive strength for the concrete mixes is Series C2 which was 39.3N/mm^2. The optimum percentage used of HSGC in producing concrete was not exceed with 30% biomass aggregate and 6% fly ash as a partial replacement with granite and cement respectively. The results obtained and observation made in this study suggest that biomass aggregate and fly ash are successfully used as partial replacement in producing for normal strength concrete but not for high strength concrete because their strength concrete don't achieve 40N/mm^2 based on British Standard.

ABSTRAK

Penggunaan konkrit berkekuatan tinggi telah menjadi semakin popular dalam Sistem Binaan Bangunan terutamanya dalam pembinaan bangunan berbilang tingkat dan juga infra-struktur. Walau bagaimanapun, konkrit tersebut adalah tidak mesra alam kerana ia mengandungi kandungan simen yang lebih tinggi yang merupakan salah satu punca utama membawa masalah kepada alam sekitar seperti kesan rumah hijau dan pemanasan global. Oleh itu, tujuan kajian ini adalah untuk menghasilkan konkrit hijau berkekuatan tinggi dengan menggunakan sisa buangan seperti aggregate biomass dan Abu Terbang dengan bahan tambah Supracoat SP800. Kajian ini akan bertumpu untuk mengenal pasti sifat bahan kimia agregat biojisim, sifat-sifat kejuruteraan konkrit dan nisbah bancuhan optimum dalam membentuk Konkrit Hijau Berkekuatan Tinggi. Sebanyak 90 spesimen kiub telah disediakan daripada nisbah bancuhan 15% dan 30% bagi bahan ganti aggregate biojisim dan 4%, 6% dan 8% bagi bahan ganti Abu Terbang. Selepas proses pengawetan basah, kekuatan mampatan bagi specimen tersebut telah pada diuji pada umur hari ke-7, 14 dan 28. Secara keseluruhannya, tahap kebolehkerjaan dan nilai kekuatan mampatan akan berkurangan dengan peningkatan penggantian granit dengan agregat biojisim. Sebaliknya, tahap kebolehkerjaan dan nilai kekuatan mampatan akan meningkat dengan penggantian simen dengan Abu Terbang. Dengan keputusan analisis yang didapati, kekuatan mampatan paling bagi konkrit hijau berkekuatan tinggi adalah 39.3N/mm^2 bagi siri C2 dengan nisbah bancuhan optimum bahan ganti 30% agregat biojisim dan 6% Abu Terbang. Keputusan yang diperolehi menunjukkan agregat biomass dan Abu Terbang berpotensi untuk konkrit bukan berkekuatan tinggi kerana kekuatan mampatannya tidak mencapai British Standard iaitu 40N/mm^2.

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LIST OF SYMBOLS/ ABBREVIATIONS/ NOTATIONS/ TERMINOLOGY

AIV	-	Aggregate Impact Value
ACV	-	Aggregate Crushing Value
ASTM	-	American Society for Testing and Materials
BA	-	Biomass Aggregate
BS	-	British Standards
COV	-	Coefficient of Variance
DOE	-	Department of Environment
EN	-	European Standard
FA	-	Fly Ash
IEA	-	International Energy Agency
LA	-	Los Angeles Abrasion
NA	-	Natural Aggregate
OPC	-	Ordinary Portland Cement
OPS	-	Oil Palm Shell
RHA	-	Rice Husk Ash
POFA	-	Palm Oil Fuel Ash
UPM	-	Universiti Putra Malaysia
UTHM	-	Universiti Tun Hussein Onn Malaysia
WBA	-	Washed Bottom Ash
XRF	-	X-Ray Fluorescence
CO_2	-	Carbon Dioxide
RAC	-	Recycled Aggregate Concrete
ppm	-	Parts per million
m	-	Mass in kg
v	-	Volume in meter cubic
ρ	-	Density in kg per meter cubic
W	-	Weight in gram

σ	-	Compressive Strength/ Stress in MPa @ N/mm^2
P	-	Maximum Compression Axial Force in Newton
A	-	Cross Sectional Area in mm^2
$<$	-	Less or Not Greater Than

CHAPTER 1

INTRODUCTION

Concrete is the most widely used construction material in the world (Aitcin, 2000; Mobasher, 2008). The main ingredient in concrete is cement, which consists of Limestone or Calcium Carbonate $CaCO_3$. During the cement manufacturing process, the ingredients used are heated to about 800-1000˚C. This process will help drive off a large amount of the Carbon Dioxide. Approximately 1kg of cement produced will release about 900gms of Carbon Dioxide into the atmosphere. An overall 95% of all CO_2 emissions from a cubic meter of concrete are from cement manufacturing (Karthik H. Obla, 2009, Meyer, 2005; Bentz, 2010; Bondar et al., 2011). Based on the U.S. Geological Survey, Mineral Commodity Summaries, the annual production of cement in Portland is estimated at 3.4 billion tons in 2011. This is responsible for about 7% of the total worldwide CO_2 emission, which is also one of the major contributing factors in global warming (Mehta, 2001).

However, there have been a number of researches conducted in an effort to reduce the CO_2 emissions from concrete. This is done primarily through the use of lowering the amounts of cement and increasing the amounts of supplementary cementitious material (SCM), such as fly ash, blast furnace slag, biomass and others (D.B. Desai et al., 2013). It is important to reduce CO_2 emissions through the greater use of SCM and natural aggregate replacement with waste material when developing sustainable concrete or green concrete. Therefore, the research done on the local green concrete is important, especially its’ application in the High Strength Concrete, which is called High Strength Green Concrete (HSGC) locally. In this context, green concrete is meant to take environmentally friendly concrete that uses less energy in its production and produces less carbon dioxide than normal concrete would. In Malaysia, agricultural activities such as palm oil, timber, rice, sugarcane etc contributed to the nation economy development but these kinds of activities also generates high amount of waste. The disposal of such waste poses an environmental problem as landfills are limited. All these kinds of waste can be turned into by-products waste after treated through combustion process at the factory which called biomass wastes. It is therefore natural to consider the use of such waste in the production of concrete especially in partial aggregate replacement purpose.

1.1 Problem Background

Malaysia, like any other developing country, considers the construction industry as one of its' main contributors to its' Gross Domestic Product (GDP). However, there are unresolved issues arising from the ongoing and widespread adoption of the traditional method of construction. Among them are the resultant fragmentation of the industry itself; delays in production and delivery time; unnecessary wastages and lack of sustainability practice (Nawi, M. N. M. et al. 2011). As a result, the Malaysian Government has been continuously encouraging the industry to use, partly or if not wholly, the Industrialized Building System (IBS), which is considered to be an important part of sustainable construction initiative (M.S.Fathi et al. 2012).

Consequently, the construction industry in Malaysia has started to embrace IBS as a method of attaining better construction quality and productivity. Hence reducing risks related to occupational safety and health, alleviating issues for skilled workers and dependency on manual foreign labor, and lastly, achieving the ultimate goal of reducing the overall cost of construction. Apart from this, it offers minimal wastage, fewer site materials, a cleaner and neater environment, controlled quality, and lower total construction costs (Pan et al., 2008, Hamid et al., 2008 and Pan et al., 2007).

High Strength Concrete (HSC) is one of the most significant new materials available in the IBS to the general public. It can be utilized in new construction and also in rehabilitation of buildings, highways and bridges (Wonchang Choi et al., 2008). HSC has been produced and is widely used in the US and Europe. The demand for HSC has also increased in Malaysia due to the booming construction of high-rise buildings and towers (Wu, D. et al., 2010). According to Muhannad Ismeik (2009), the benefits of using HSC are: 1) to put the concrete into service at much earlier age; 2) to build high-rise buildings by reducing column sizes and increasing available space; 3) to build superstructures of long-span bridges; and 4) to satisfy the specific needs of special applications such as durability, modulus of elasticity and flexural strength.

In Malaysia, the positive successes reported from field and laboratory-based studies have proven the sustainable construction are practical and can be applied in Low Carbon Cities Framework and Assessment (KeTTHA, 2011), and Green Building Index (GBI) (Boon Che Wee, 2013). However, the green concrete has not been widely applied in HSC practice in local construction industry. Sometimes, its' usage has been discouraged by some professionals, who doubts it design technique, and doesn't accepted it contribution & performance. So, in order to effectively use HSGC in Malaysia, there is a need for cooperation between researchers, together with local industry experts, to accurately devise an effective concrete mix design. Cooperating to determine its compressive strength, this is used as an essential parameter in the structural design application of the Industrialized Building System (IBS).

1.2 Research Problem

To achieve the High Strength Green Concrete, the use of supplementary cementitious materials (SCMs), recycled aggregates and other industrial wastes are encouraged. This could potentially reduce the environmental impacts of concrete production (Lepech et al., 2008). According to Mannan and Ganapathy (2004), using agricultural and industrial wastes as replacement materials in the concrete industry has dual advantages of cost reduction and a better way of waste disposal. They also pointed out that the material recovered from the conversion of these wastes into useful materials benefits both the environment and the conservation of natural resources. In this study, aggregates from recycled waste biomass fly ash are defined as alternative aggregate (AA). The SCMs and AAs are called “green” raw materials in this paper.

Although the sustainability of concrete can be improved by using waste materials, adding SCMs or AAs could impact properties of concrete, such as compressive strength, workability, and etc., which are extremely important for its’ applications. Also, production of concrete using waste materials is not necessarily considered sustainable unless the concrete has been proved to be durable (Lepech et al., 2008). Extensive studies have also been carried out to identify waste materials that can be used as SCMs and AAs in concrete production. For example, biomass fly ash have been widely identified as SCMs (Topcu and Boga, 2010; Bondar et al., 2011; Limbachiya et al., 2012). Different waste materials that could be potentially used as aggregates have also been explored and concrete properties have been tested (Manso et al., 2006; Polanco et al., 2011; Trussoni et al., 2012). Despite all the efforts in exploring the use of waste materials in concrete, a gap exists between academic research and industry practice. Sometimes materials studied in academic research have critical restrictions that limit their wide applications in the industry. For example, research on recycled concrete aggregate (RCA) seems promising by recycling waste concrete material from demolition, which would otherwise go to landfill into concrete production. However, inferior quality of this type of concrete, such as lower strength, has been recognized (Limbachiya et al., 2012).

1.3 Research Aim and Objectives

The aim of this research is to identify the performance of high strength green concrete with biomass aggregate towards environmental sustainability and the current issues of “green” concrete production and implementation of High Strength

Green Concrete in Industrialized Building System (IBS). The following are the objectives in order to achieve the research aim:

1. To identify the chemical properties of biomass aggregate.
2. To determine the engineering properties of High Strength Green Concrete.
3. To determine the optimum mix design of the High Strength Green Concrete.

1.4 Research Scope

This research is related to green or sustainable high strength concrete study involving the experimentation by using compression machine to examine the compression strength and the measured parameters. The parameters comprised of cement content, fly ash content, water cement ratio, fine aggregate content and coarse aggregate content, recycle biomass aggregate, and add mixture (M.A. Rashid & M.A. Mansur, 2008). The grade of high strength concrete used in this research will be limited to $50N/mm^2$ since this standard is commonly used in Sarawak.

To achieve the above objectives, concrete specimens were produced and tested in the laboratory. In the first concrete mix design, the natural aggregate was replaced, by weight, with 15% and 30% by biomass aggregate. In the second concrete mix design, the cement was replaced, by weight, with 4%, 6% and 8% by fly ash. In third concrete mix design, the water cement with a ratio of 0.35 was used in the mixes to carry out the 7-day, 14-day and 28-day compressive strength.

1.5 Significance of Research

In recent decades, the construction of sustainable green concrete using fly ash and biomass aggregate has been widely used for the application in the normal and light weight construction material. However, sustainable green concrete using biomass aggregate in High Strength Concrete studies is hardly available in Malaysia. Therefore, the benefits expected from this research are:

1. To provide guidelines for concrete mix composition that can be used in the formulation of High Strength Concrete for the local market.
2. That the proposed concrete mix design can reduce the overall usage of ingredients of natural resources aggregate up to 30% in concrete mixture.
3. That the proposed concrete mix design will be the best solution for local plywood industries by recycling fly ash disposals in their by-product wastes instead of discharging to landfill.

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