RECYCLING OF MUNICIPAL SOLID WASTE INCINERATION ASH AS RAW MATERIAL IN COLD-BONDED LIGHTWEIGHT AGGREGATE

by

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LIST OF ABBREVIATIONS

%	Percentage
ACI	American Concrete Institute
AIV	Aggregate Impact Value
AlO	Alumina
APC	Air Pollution Control
ASTM	American Society for Testing and Materials
BA	Bottom Ash
BALA	Bottom Ash Lightweight Aggregate
BASLWAC	Bottom Ash Semi-Lightweight Aggregate Concrete
BS EN	British Standard (Eurocode)
CaO.	Calcium Oxide
CIDB	Construction Industry Development Board
CO_2	Carbon Dioxide
FA	Fly Ash
FALA	Fly Ash Lightweight Aggregate
FASLWAC	Fly Ash Semi-Lightweight Aggregate Concrete
FeO	Ferric Oxide
FTIR	Fourier Transform Infrared
kg/m^3	Density
KO_2	Potassium Dioxide
LECA	Lightweight Expanded Clay Aggregate
LWA	Lightweight Aggregate
m	Meter
m^3	Volume
MgO	Magnesium Oxide
mm	Millimeter
MnO	Manganese Oxide
MPa	Mega Pascal
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
N/mm^2	Unit Density
NaO	Sodium Oxide
NDT	Non-Destructive Test

NWA	Normal Weight Aggregate
NWC	Normal Weight Concrete
OPC	Ordinary Portland Cement
PSA	Particle Size Analysis
RR	Room-Room
RW	Room-Water
SEM-EDX	Scanning Electron Microscope – Electron Dispersive X-Ray
SiO	Silica
SLWAC	Semi-Lightweight Aggregate Concrete
SO	Sulphur Monoxide
TiO	Titanium Oxide
UPV	Ultra Pulse Velocity
WTE	Waste to Energy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

Kitar Semula Abu dari Insinerator Sisa Pepejal Perbandaran Sebagai Bahan Mentah dalam Agregat Ringan Ikatan-Dingin

ABSTRAK

Kajian ini memfokuskan tentang pembangunan agregat ringan baharu yang mempunyai ciri-ciri yang setanding dengan agregat semulajadi iaitu granit. Objektif-objektif utama dalam kajian ini ialah untuk memeriksa potensi kegunaan abu kitar semula dari insinerator sisa pepejal perbandaran (MSWI) sebagai bahan mentah dalam pembuatan agregat ringan (LWA) melalui kaedah pempeletan ikatan-dingin. Abu-abu yang digunakan adalah diambil dari Loji Insinerator Cameron Highland, Malaysia yang boleh dibahagi kepada dua jenis iaitu abu bawah (BA) dan abu terbang (FA). Ciri-ciri BA dan FA dikaji dengan menggunakan X-Ray Fluorescence (XRF), Scanning Electron Microscope (SEM) dan ujian ketumpatan. LWA yang terhasil dinamakan sebagai agregat ringan abu bawah (BALA) dan agregat ringan abu terbang (FALA). Kedua-dua BALA dan FALA melalui dua keadaaan pengawetan berbeza selama 28 hari iaitu keadaan udara-udara (RR) dan udara-air (RW). Peratus BA dan FA yang digunakan dalam kajian ini ialah 10 %, 20 %, 30 %, 40 % dan 50 % untuk penggantian sebahagian simen dan saiz agregat ditetapkan antara 10 mm hingga 20 mm dan berbentuk bulat. Ciri-ciri bagi BALA dan FALA yang terhasil dalam kajian ini diperiksa merangkumi ketumpatan pukal, penyerapan air, nilai impak agregat (AIV) dan graviti tentu. Lain-lain ciri fizikal termasuklah warna dan tekstur juga dikaji. Potensi penggunaan BALA dan FALA dalam konkrit juga disiasat dengan memilih sampel yang optimum bagi kedua-dua agregat yang dimasukkan ke dalam pembuatan konkrit agregat ringan (SLWAC). 30 spesimen SLWAC telah dihasilkan yang mempunyai nisbah air-simen sebanyak 0.5 dan peratusan penggantian agregat ditetapkan pada 20 %. Ciri-ciri SLWAC ini periksa termasuklah kebolehkerjaan, ketumpatan, penyerapan air, penyerapan air kapilari, halaju ultra-nadi (UPV), kekuatan mampatan dan kebolehtelapan. Pengagihan BALA dan FALA di dalam SLWAC juga diperiksa melalui keratan rentas konkrit. Daripada keputusan kajian terhadap LWA dapat dilihat dengan jelas bahawa kandungan sebanyak 20 % bagi BA dan FA merupakan peratusan terbaik penggunaan abu dalam menghasilkan LWA yang berkualiti. Ketumpatan pukal bagi BALA ialah 739.53 kg/m^3 dengan penyerapan air 20 % dan AIV 13.94 %. Manakala, bagi FALA, peratus optimum ialah seperti berikut; ketumpatan pukal 716.72 kg/m^3, penyerapan air ialah 19.7 %, AIV 13.80 % dan graviti tentu 1.670. Walau bagaimanapun, bagi SLWAC, keputusan menunjukkan dengan menggunakan BALA dan FALA di dalam konkrit akan meningkatkan kebolehkerjaan konkrit seperti yang dinyatakan dalam nilai runtuhan. Kesan nyata pengurangan nilai ketumpatan pukal dalam LWA dapat dilihat melalui pengurangan nilai ketumpatan bagi SLWAC. Kekuatan mampatan bagi FASLWAC adalah setara dengan konkrit biasa (NWC). Kedudukan BALA dan FALA yang teragih secara seragam dalam konkrit adalah dipercayai menyumbang kepada ciri-ciri SLWAC.

Recycling of Municipal Solid Waste Incineration Ash as Raw Material in Cold-Bonded Lightweight Aggregate

ABSTRACT

This study focusses on the development of new lightweight aggregate (LWA) that eventually have comparable properties with existing natural aggregate which is granite. The main objective of this study is to examine potential use of recycled municipal solid waste incineration (MSWI) ash as raw material in LWA production with a method of cold-bonded pelletization process. The ashes are collected from Cameron Highland Incineration Plant, Malaysia that can be divided into bottom ash (BA) and fly ash (FA). The properties of BA and FA are studied by means of X-Ray Fluorescence (XRF), Scanning Electron Microscope (SEM) and apparent density test. The LWA is denoted as bottom ash lightweight aggregate (BALA) and fly ash lightweight aggregate (FALA). Both BALA and FALA have experienced two different curing process for 28 days namely room-room (RR) and room-water (RW) curing conditions. The percentage of BA and FA used in this study were 10 %, 20 %, 30 %, 40 % and 50 % of partial cement replacement and the size of aggregate is fixed between 10 mm to 20 mm with circular shape. The properties of BALA and FALA produced in this study is examined including loose bulk density, water absorption, aggregate impact value (AIV) and specific gravity. Other physical properties including colour and texture are also being investigated. Potential use of BALA and FALA in concrete is investigated by selecting optimum samples of both aggregates to be incorporated in the manufacturing of semi-lightweight aggregate concrete (SLWAC). 30 specimens of SLWAC were produced having water-cement ratio of 0.5 and percentage of aggregate replacement is fixed at 20 %. Characteristics of SLWAC were examined including workability, density, water absorption, capillary water sorption, ultra-pulse velocity (UPV), compressive strength and permeability. Distribution of BALA and FALA in SLWAC is examined through cut-section of concrete. From the results of LWA it is clearly seen that 20 % BA and 20 % FA were the best percentage of ash used to produce good quality LWA. Loose bulk density of BALA selected is 739.53 kg/m^3 with water absorption 20 % and AIV 13.94 %. Meanwhile, for FALA, optimum percentage is as follows; loose bulk density 716.72 kg/m^3, water absorption is 19.7 %, AIV 13.80 % and specific gravity 1.670. However, for SLWAC, the results show that by incorporating BALA and FALA in the concrete improved the workability of concrete. The obvious impact due to the reduction of loose bulk density in LWA can be evident by the reduction of apparent density of SLWAC. Compressive strength of FASLWAC is comparable with NWC. Well-distributed BALA and FALA in concrete specimens is believed to contribute to the properties of SLWAC.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Many types of wastes are generated each day all over the world which led to the pollution of the environment and reduction to the quality of life. In early decades, the management and disposal of solid waste did not raise a major concern as the number of population is still small and requires small land area to cater for its disposal. However, along the years, the accumulation of solid waste is increased and the existing land is insufficient. Due to the scarcity of land, it is almost impossible to acquire new land as landfill area, especially in urban area. Therefore, with the tremendous increase of solid waste being generated, the recycling and reuse of waste materials is important in order to preserve the environment because in matter of time, the deterioration of our environment will become severe if not treated and handled efficiently.

Incineration process was found to be an efficient way of controlling the volume of solid waste as it helps to change the physical properties of waste into smaller particles which is bottom ash (BA) and fly ash (FA) and other residue such as flue gas and heat. It has advantageous as the energy can be harvested and the ash can be reused to form new materials. These ashes are about 5% to 30% of the total solid waste being burned during the incineration process (Cioffi, Colangelo, Montagnaro, & Santoro, 2011). The recovery of the ashes from the incineration process and converting it into other usage have been started as early as 1996. Studies by numerous researchers shows that ash from the incineration process is proven to be valid and possible to use with several treatment (Müller & Rübner, 2006; Cioffi et al., 2011; Colangelo, Messina, & Cioffi, 2015;

Gesoğlu, Özturan, & Güneyisi, 2007; Güneyisi, Gesoğlu, Booya, & Mermerdaş, 2015; Kim, Shin, & Cha, 2013; Quina, Almeida, Santos, Bordado, & Quinta-ferreira, 2014). However, most of these studies only focussed on the usage of the ashes in their original forms with minimal modification by prior treatment. The significant results from their studies indicates that BA and FA promised good potential for future usage especially in civil engineering field including manufacturing of aggregate and concrete. It is well-known that MSWI BA vary according to the sources of solid waste and incineration process (Tang, Florea, Spiesz, & Brouwers, 2016).

Concrete have been chosen as main material in building structures for many years. Generally, concrete can be divided into several categories, depending on the raw materials used to produce concrete. It also depends on the characteristics of the concrete such as density, strength and durability. Figure 1.1 shows a classification of concrete that are most widely used as construction materials.

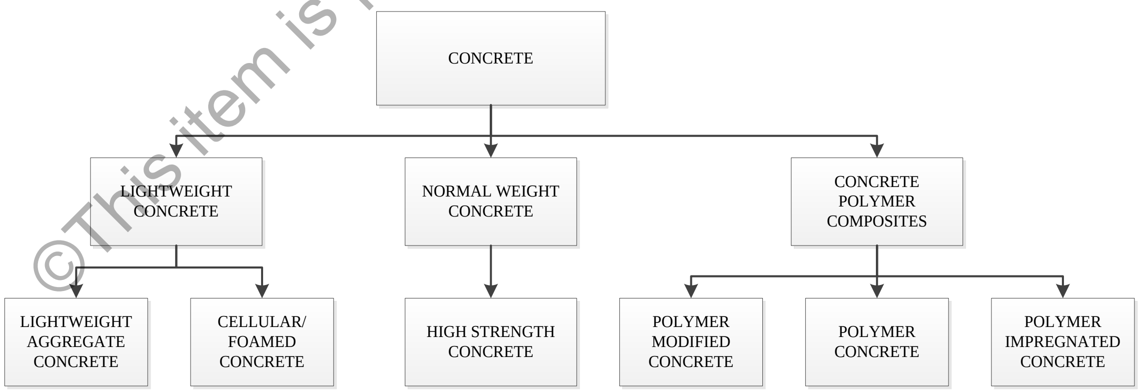

Figure 1.1 Classification of concrete

Builders and engineers throughout the world are paying more attention to the application of lightweight aggregate as it can contribute to lower density of concrete. The interest of using lightweight concrete is at high if it can contribute to comparable compressive strength. If lightweight concrete with comparable high strength is realised, the section size of any structural member could be reduced due to lighter permanent action imposed to the member especially from upper structures. This may permit not only large space availability but also reduce the usage of reinforcement and cement quantity. Lightweight concrete can be sub-divided into two main categories, which is lightweight aggregate (LWA) concrete and cellular concrete. In LWA concrete, the main materials used were basically LWA, cementitious material, fine aggregate and water. Some admixtures may be added into the mixture if certain property such as for ultra-high strength concrete where super plasticisers is required.

LWA can be obtained either from natural resources such as oil palm shell or from artificial aggregate where it has been produced from a factory (U. Johnson Alengaram, Muhit, & Jumaat, 2013; Gunasekaran, Annadurai, & Kumar, 2015). Various types of LWA can be produced such as expanded clay, sintered fly ash (Terzić, Pezo, Mitić, & Radojević, 2015) or air-cooled blast furnace pelletized slag (Abouhussien, Hassan, & Ismail, 2015). LWA can be manufactured either by cold-bonded pelletizing process or by sintering process which will cause higher energy consumption. In cold-bonded pelletizing process, the agglomeration of aggregate pellet was helped by water as an agglomeration agent. This is a procedure where finer particles were merged with each other to become larger solid particles which resulted in lightweight due to presence of small pores. Meanwhile, sintering method usually expose the pellets to high temperature and normally up to 1200 °C in various time periods. Sintering has a common application in mass production of aggregate despite being an energy intensive process (Cheeseman, Makinde, & Bethanis, 2005; Sarabèr, Overhof, Green, & Pels, 2012).

On the other hand, cellular concrete was produced with the aid of foams to provide pores in concrete. Generally, cellular concrete is typically accomplished by maximizing the quantity of fine materials in the mixture which could be obtained by incorporating mineral admixtures such as fly ash, bottom ash, and volcanic ash; cement kiln dust or metakaolin, adding high range water reducer admixtures or minimizing the usage of coarse aggregate content in the mixture. Compressive strength of cellular concrete is usually lower than normal weight concrete (NWC) but this property can be improved by enhancing the microstructure of the concrete.

Therefore, more relevant studies of new composite materials need to be done to fulfil these requirements. One of the significant ways to produce sustainable and green materials is by using waste by-products.

1.2 Background of the Study

Incineration process has proven to be an effective way to help reducing the escalation of solid waste in landfill. If the design and managerial aspect can be improved, it is surely worth to increase the amount of incineration plant all over Malaysia especially in the area of limited land by building the Municipal Solid Waste Incineration (MSWI) Plant. Currently, there are 4 main incineration plant in Malaysia which were located at Cameron Highland, Pulau Langkawi, Pulau Pangkor and Pulau Tioman. The incinerator residues would later be used in the other different area.

Incorporation of various types of admixtures into aggregate has led to the emergence of new trends in concrete and aggregate-related studies to improve mainly but not limited to strength and durability of concrete and aggregate elements. In recent years, many works have been devoted to improve the quality of concrete. In spite of their importance, more sustainable and economic construction materials are very limited in the market. Therefore, an alternative way to achieve this aim is by creating new strong, durable and potential material that can be utilised in concrete manufacture industry. LWA can be replicated to have comparable properties with that well-known normal aggregate. Wide variety of the LWA source and producing method have resulted in distinguishing behaviour among existing lightweight aggregate concrete (LWAC).

In this study, the LWA that possessed enhancement in some durability characteristics was developed. The main aim is to establish optimal properties combination that would maximize LWA concrete performance so it could match to that of standard concrete. Two main residues ash from MSWI plant were recycled and reused as an admixture in the production of lightweight artificial aggregate. These ashes are bottom ash (BA) and fly ash (FA) and are employed as a partial cement replacement in aggregate making process. These ashes were chosen because they can easily be found in abundance in MSWI Plant in Malaysia and usually were dumped at the landfill after the burning activities. Since this artificial LWA should be light in density, foaming agent was used to produce sufficient amount of foam that can be utilised in the mixing process. The introduction of foams in the aggregate mixture will creates sufficient amount of pores that will help to lighten the aggregate. The type of foaming agent used in this study was Polyoxyethylene Alkyether Sulfate with 1:33 foaming agent to water ratio as provided by the manufacturer.

Furthermore, only cold-bonded pelletizing technique was employed in this study to avoid excessive heat usage. The performance of concrete incorporated with these LWA was examined and studied from an engineering point of perspective. To date, the engineering properties of LWA made from BA and FA with the aid of foams were very limited and incomplete. Therefore, this study was initiated to fill the gap in knowledge of LWA which were made from incineration waste products.

1.3 Problem Statement

The huge amount of solid waste creates a massive stock piles of waste at the landfill and creates serious issue to the environment. When rains come, the rainwater will penetrate through this pile of waste and the murky water just flows into nearby river. This horrendous mass needs to be disposed in proper manner in order to solve the environmental pollution. At all over the world, the most convenient way for the authorities to handle the solid waste is by providing a dedicated land as a landfill. These landfills require huge areas of land and requires more money. The numbers of solid waste being dumped is escalating tremendously year by year and dumped in these landfills be it sanitary landfill or open dumping. Figure 1.2 shows significant amount of solid waste being dumped at Pulau Pangkor Incineration Plant.

Figure 1.2 Solid waste at Pulau Pangkor Incineration Plant

For most developed nations, most proper way to dispose the solid waste is by burning all of these waste using the incinerator. Incinerator is a facility that provides a service of burning large volume of waste especially industrial waste in huge furnace with high temperature until it was converted into ash mainly bottom ash and fly ash, flue gas and heat, which in most countries including Malaysia it is well known as MSWI Plant. After the incineration process is finished, usually BA will be sent to the landfill and will be covered by landfill liner for several layer and the FA is sent to Alam Flora for further treatment. The treatment of FA will cost thousands of money and disastrous if left unattended and handled properly. Thus, several attempts have been made from previous researchers to investigate the potential of these ashes to be utilised in the construction industry including manufacturing a concrete or brick, as coarse aggregate in concrete or incorporated them in the blended cement. Figure 1.3 shows an example of BA and FA collected from MSWI Plant.

a) Bottom ash b) Fly ash

Figure 1.3 Samples of MSWI ashes a) Bottom Ash, and b) Fly Ash

As for the development of aggregate, it can be classified into LWA or normal weight aggregate (NWA). In order to ensure the compressive strength of concrete is satisfactory, NWA is still need to be included in the mix proportions. It is well known that NWA can contribute to the strength of the concrete. In spite of its high strength quality, the use of NWA resulted in increasing of concrete self-weight. Thus, the introduction of LWA in concrete mixes will help to overcome the density issue. Though LWA cannot always substitute normal concrete for its strength potential, it still has its own advantages like reducing the total dead load imposed on the structural components and thus, will undoubtedly reduce the overall construction cost.

LWA can be produced by either thermal hardening method or cold-bonding cement-based pelletizing technique. In thermal treatment process such as sintering, autoclaving and steam curing, pelletizing process involve high temperature which sometimes up to 1200 °C (Lu, Chen, Chuang, & Wey, 2015). This will increase the overall cost in construction. Most researchers often choose thermal hardening method