Treated Municipal Solid Waste (Biomass) Based Concrete Properties – Part I: State of the Art

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Abstract. Municipal Solid Waste (MSW) management is a worldwide problem growing with the increase of global human population. The practice of incinerating garbage has ceased in some parts of the world because of air contamination and other public health issues. Environmental impact of landfilling is ever increasing. There is clearly a need to adopt cost-effective alternatives to treat MSW. This paper is a part of a major work that considers MSW based biomass as a partial replacement of sand in concrete. The product of the global work is an exciting and eco-friendly alternative for the building industry, especially concrete intended for certain types of applications in the construction industry such as temporary works. Here, in this paper, an overview of the state of the art on the topic is presented.

Keywords: Municipal Solid Waste, Biomass, Concrete, Mechanical Properties.

1 Introduction

1.1 Technology of Waste Treatment

Waste generation is an inevitable by-product of human activities. On a global scale, approximately 3.5 million tonnes of municipal solid waste (MSW) are being produced daily [1]. In the year of 2010-2011, Australia alone has a waste production of 2.2 tonnes per capita. Although 60% of this generated waste was either recycled or recovered, there is still 40% of the remaining sent for landfill disposal. Over time, the degradation of the waste resulting in the landfills to emit leachate and gases to the environment and waterways. It is estimated that landfills have contributed approximately 20% of the global greenhouse gases (methane and carbon dioxide) emissions and leachings of toxic chemicals, such as mercury, arsenic, beryllium, boron, cadmium, lead, thallium and hydrocarbon compounds, into the environment [1], causing harmful threats to human health, environment and ecological system. Furthermore, landfills cause nuisance, such as flies, odours, smoke and noise, while the increase in vermin surrounding landfills becomes an issue with other adverse health effects, such as congenital disabilities, respiratory illnesses and even cancer [2].

However, as the technology for waste management improves, there are many methods to treat MSW effectively and environmentally friendly. For example, Bioelektra Group has invented the Advanced Recycling Technology (ART) of MSW for waste treatment. It operates unsorted MSW using the innovative RotoSTERIL mechanical heat treatment technology. This revolutionary method is based on a new incredibly useful technological process which uses the autoclave roto sterile BCG 7000, a machine that has been designed to treat unsorted MSW in the sterilization process.

The waste is physically and chemically processed. The waste is also sterilized to eliminate odours. Besides, the MSW collected from the household will be transported to the ‘reception hall', which is the only place that the workers contact the MSW. This design of the waste management facility has significantly reduced the growth of bacteria and pests that brings harmful threats to the human and surrounding environment. Materials such as metals, plastic and glasses are separated during different stages of separation using advanced technology (i.e. magnetic separator, laser detection optical sorter etc.) leaving 30 per cent of the entire processed waste as biodegradable fraction also called biomass.

Finally, all the separated fractions are collected and transferred to be recycled recovered and reused, leaving no waste to be landfill, promoting the circular economy and sustainable development [3]. Bioelektra Group has a pilot plant in Rozanski in west Poland which has been operational for nine months, and it has proven the reliability and practicality of the ART technology on recycling MSW.

1.2 Pollution by Construction Material Production and Green Alternatives

The destruction of the environment always tags along with the development of the city and technology. These human activities have resulted in many major natural severe disasters such as wildfires, tsunami, flooding and drought event, depletion of the ozone layer, rising of sea level, global warming etc.

The construction and mining industries have contributed a significant proportion to these events. The activity of producing and transporting construction material has emitted a high amount of carbon dioxide (CO_2). Amongst all the construction material, the highest CO_2 producing ingredient is cement [4]. Cement production in China was 1.39 billion metric tons in 2008 [5], accounting for 50% of the world's output [6]. Large quantities of air pollutants are emitted from cement production, including SO_2, NO_X, CO, and PM, and therefore cement industry has been identified as a primary source of pollution in China. Cement production is expected to reach 3.5 billion metric tons by the end of 2050 if its consumption remains constant globally [7].

The fundamental utilization of Ordinary Portland Cement (OPC) is to make concrete and mortar. The reason why cement is popular and widely used over other construction material is due to its ability to hold the structure together and is relatively cheap compared to other construction material such as steel and timber. To promote sustainable and green construction in the industry, the behaviour of including agricultural waste and industrial waste into concrete or mortar have been studied and implemented in the field. There are several benefits associated with it, which provides for enhanced mechanical properties, energy-efficient and cost-effective.

1.3 Research Objectives

This research aims at reducing the amount of municipal waste produced by human activities goes into landfill. Using treated municipal waste by ART technology in the construction industry, specifically in concrete production, has been questioned. The work is reported in two Parts. Part I is the present paper where an overview of the state of the art on the topic is presented. The Part II is related to the experimental program and the corresponding findings.

2 State of the Art

2.1 Utilization of Organic Biomass Ashes in Australian Construction Industry

The use of organic and inorganic wastes has always been a featured topic and has attracted more attention in recent years [8]. One of the major drivers is rapid population growth and urbanisation, which result in ascending waste treatment demand [9]. Currently, the most commonly used methods for waste treatment are landfill and waste-to-energy incineration, which has been a long-term environmental concern [10]. Common issues with landfill include contamination of land and underground water [11] due to leaching and the high cost of maintenance associated with it [12], which makes it a non-economic and risky way of waste treatment.

Although waste-to-energy (WTE) is widely adopted to transform waste into energy [13], Connett [14] argued that it is not a suitable way of treating waste, considering sustainability as the key issue in the twenty-first century. Besides, air pollution due to combustion [15] and its low efficiency [16] prompt new ways of waste treatment need to be investigated.

Another driver is that cement production is one of the significant sources of greenhouse gas emission including sulfur dioxide, nitrogen oxides, carbon monoxide, particle matters and carbon dioxide [7, 17] and it generates 5-7% of all anthropogenic carbon dioxide. Furthermore, there are potential hazards affecting workers' health as it is being handled during transportation and occupation [18].

Moreover, China's new policy of tightening controls on importing foreign waste has pressurised first-world countries like Australia relying on exporting for waste treatment. Additionally, it is suggested some other major importers like Malaysia and Thailand have also announced a tightening of their waste importing policies while others were taking actions forcing Australia to look for new ways to treat or export approximately 1.29 million tonnes of waste [19]. Despite the political issues associated with these changes, it is crucial for the world, especially for countries like Australia, relying on exporting for waste treatment.

2.2 Organic Biomass Ash from ART

The material in this research will be focusing on is MSW treated by Vortex-oscillation technology. MSW quite differ from agro-waste and is widely available from every household. agro-waste consists of animal waste (e.g. manure, animal carcasses), crop waste (e.g. cornstalk, sugarcane bagasse, pruning), food processing waste and hazardous and toxic waste (e.g. pesticides, herbicides, insecticides) [20]. In contrast, MSW comprises of paper, plastic, cardboard, metals, glass, rags, kitchen waste, food waste, rubber, ash and fine etc.

The treatment of MSW through Vortex-oscillation technology involves sequential step and involves sterilization of the waste material. Later organic part is then separated from the inorganic component and further treated as aforementioned. The final product ready for mixing is low-weight, not reactive and having a fibre-like microstructure [8]. This method minimises treatment cost and environmental impact while also having a positive social impression. According to Sofi et al. [8], the sustainability to use treated MSW (TMSW) produced by the ART technology as partial replacement of construction material is expected and demonstrated in the future. According to Bioelektra, the TMSW created is sterile and free of contaminants [3]. Besides, it has high energetic value, low humidity and other physical characteristics which make it an ideal alternative replacement of the construction material for green energy production.

3 Previously Investigated Materials

The increasing need for creating eco-friendly construction materials as sustainable solutions to both waste treatment and building material production inspires professionals with diverse backgrounds. A wide range of materials has been studied by scholars from different parts of the world. Among these studies and researches, agro-waste like rice husk [9, 21] and its ash [18], bagasse [21], oil palm shell [22], corn [10], oyster shell [9], ground coffee waste [23], coconut shell [24] and plant ashes [25] and industrial waste like wood ash [26], treated waste foundry sand [12], wood fibre [27], biomass boiler ash and green liquor dregs from paper from waste paper industry [28] are investigated. Fibres material is mostly used to replace parts of the aggregates in the concrete while most of the ashes were used to replace cement in the mixture.

Even though the wide range of waste materials have been studied, the use of municipal waste in the fabrication of concrete has yet to be further investigated. It has been partially explored by Syarif et al. [21] but only as a component of the “recycling organic waste” which is treated by burning to a temperature of 1450 °C before it is ready for mixing as part of concrete.

3.1 Characteristics of Biomass Concrete

Mechanical Properties

Organic waste materials, mainly biomass ash from various agriculture waste act differently when participating as part of the cementitious mixes depending on their chemical characteristics and the amount being added.

According to Martínez-Lage et al. [28], concrete with 10% paper ashes replacement of cement has higher compressive strength at 7 and 28 days of maturity compared to the OPC concrete. Besides, this statement is further supported by a literature review [29] stating that there is an increase in mechanical strength when the substitution rate of cement to wood fly ash is at 10%. However, there is a result showing that the higher substitute rate of cement in the concrete, the lower the strength of the concrete [8].

A replacement of 0% - 20% of either binder or aggregates in cement is most widely experimented by researchers, whereas some tested higher replacement rate of 40% [30]. Generally, additional waste material would reduce the compressive strength and flexural strength as supplementary waste material would dilute the cement within the mix and absorb water, reducing pozzolanic reaction rate [31].

Most studies have tested a replacement rate of 20% of the cement and the result for this proportion level of waste replacement provides an adequate strength of the concrete [9, 11, 12]. However, Sofi et al. [8] tested the vortex-treated biomass and the sample containing 20% was still wet and did not bind together. Therefore, they concluded that the maximum dosage of vortex-treated biomass should not exceed 15%. The vortex-treated biomass is also the material being studied in this research. The conclusion from the previous research helps to identify a proper range of dosage for the replacement material.

Workability

Workability as another critical feature of concrete mix is also affected by adding waste replacements, especially biomass ashes. The smaller particle size of biomass ashes gives it a larger surface area to react with other materials, which leads to the increased water demand of the concrete mix and reduces consistency to maintain required slump value [15]. Certain materials such as bamboo, sisal and oyster shell also have higher water absorption ability to cause increased water demand [10]. It is commonly known that the higher amount of water in the concrete mix will primarily reduce the strength of hardened concrete; this makes workability become one of the challenges of using biomass materials as a replacement in concretes.

However, some researchers have been trying to study concrete with biomass component (mainly agro-waste) [29, 31]. They utilize superplasticizer to improve the workability of the concrete mix and metakaolin to enhance the strength of the hardened concrete [29, 31]. The researches show that the addition of superplasticizer into the mixture has successfully increased the workability of the concrete mix. Nevertheless, from these literature reviews, there is no equation or ratio to determine the dosage of superplasticizers. Therefore, it can be concluded that the dosage of superplasticizers is dependent on the targeted slump of each research. In this research, superplasticizers will also be incorporated into the concrete mixture to enhance concrete performance.

3.2 Factors affecting Concrete Strength

Aggregates

Aggregates account for about 60 to 80 per cent of the concrete volume and are approximately 70 to 80 per cent of its weight. Therefore, it is imperative to add the right aggregates into the concrete mix to obtain satisfactory strength. Aggregates will determine the concrete's elastic, thermal properties and dimensional stability of the concrete. Aggregates' features such as toughness, shape, size, density, soundness and specific gravity will also determine the concrete's mechanical properties and workability [32]. According to Haque et al. [33], the compressive strength of the concrete increases with larger aggregates. Vilane and Sabelo [34] stated that increase of aggregate size will improve the workability of the concrete. However, Ogundipe et al. [32] claimed that a particular aggregate size in a specific concrete mix gives optimal compressive strength and using larger aggregate will decrease the strength of the concrete. Also, finer aggregates are recommended in the concrete mix to make it more resistant to flexural stresses.

Curing Method

Different curing methods will affect the concrete strength. According to Araldi et al. [35], humidity and temperature will affect the behavior of concrete. There are several curing methods such as sprinkle of water, membrane curing and steam curing etc. The most common practice for concrete curing found in lots of researches is standard curing in which the samples are submerged into water at room temperature at 23 ◦C. Li, Wang and Yang found that steam curing has satisfactory performance on the removal strength of concrete with large amount of mineral admixture like FA and GGBS [36].

Water-to-Cement Ratio (w/c)

For pure OPC cement with certain amount of cement content, the lower w/c ratio contributes to higher compressive strength [37]. This is due to the decreased distances between cement particles when the w/c ratio is lower[38]. However, the use of very low w/c ratio could adversely affect the workability [37]. According to the experiment conducted by Felekoğlu et al. [39] on fresh self- compacting concrete, the optimum water to cement (w/c) ratio ranges from 0.48 to 0.6. Besides, Elinwa and Mahmood [40] utilized w/c ratio of 0.565 in the wood ash concrete. Moreover, due to the existence of carbon which will promote the water absorbability in the concrete will result in reduced workability of the cement paste. Similarly for the biomass concrete, the biomass as fiber material could absorb water and reduce workability of concrete. Therefore, superplasticizers shall be used in the experiment to achieve targeted workability.

4 Conclusions

Based on the literature review and on the previously investigated materials, it could be concluded that incorporating municipal solid waste like biomass in concrete can produce more sustainable concrete. It helps in reducing waste production and preventing more waste to go into landfill. The biomass concrete should be air-cured as the municipal waste in the concrete will absorb more water and become weaker if it is cured underwater. It is crucial to check such possibility in an experimental program, which is reported in the Part II having the title ‘Treated Municipal Solid Waste (Biomass) based Concrete Properties – Part II: Experimental program’[38].

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