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Necessity and Opportunity of Sustainable Concrete from Malaysia's Waste Materials

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Abstract: The sustainable concrete (SC) involves reduction of the amount of polluting and carbon dioxide (CO_2) gases emitted during the creation of concrete, more efficient use of waste materials, development of low-energy, long-lasting, flexible buildings and structures exploiting the thermal mass of concrete in a structure to reduce energy demand. Waste materials (WM), when properly processed, have shown to be effective as construction materials and have the ability to satisfy the design specifications. During recent decades, huge researches have been carried out for the use of biogenic wastes - palm oil fuel ash (POFA), rice husk ash (RHA), sawdust ash/ash from timber (AFT) and bagasse ash - and industrial waste (slag, silica fume, fly ash) as constituents of cement and concrete. Recently, about 0.3 million ton of POFA is produced annually in Malaysia. Still now, there are no remarkable uses of these ashes. These are only dumped into environment without any commercial return; hence pollution is observed, disposal problem has also been happened. Similar difficulties have been arisen by slag, RHA, and AFT. All of these WM contain a high amount of silicon dioxide in amorphous form and they are proved as pozzolanic materials in concrete production. Therefore, SC can be produced using WM in cement or concrete and they also contribute to: reduce CO_2 emission, make more durable and cost effective concrete, save energy by consumption of less cement in concrete production, solve disposal problem by the effective consumption of waste. In this paper, a review on the utilization of WM as an alternative of cement for the production of SC has been presented. The necessity and opportunity of producing SC from Malaysia's WM is mentioned. The pozzolanic activity, benefits of supplementary use of WM in cement and concrete have also been cited here. Based on the available information from literatures, it can be concluded that effective consumption of these WM as a replacement of cement will promote researchers of concrete technology to investigate sustainable way of saving material, mainly cement, and production of SC. The use of WM in concrete is practical, valuable and logical for the production of SC which is one of the best solutions for the saving of energy and for comfortable survival of human life in Malaysia as well as in the planet.

Key words: sustainable concrete, waste materials, CO_2 emission, pollution, energy conservation.

INTRODUCTION

In the modern civilized world, due to growing population and life demand the construction of buildings and infrastructures have been increased rapidly. Among the other construction materials, concrete is one of the most versatile and widely used man-made building materials and has gained popularity for its multiple advantages: easiest manufacturing procedure, strength and durability properties at normal environment. For the development and urbanization of the society, it plays a prime role in many aspects of everyday life - from the buildings we work and live in, to the roads, tunnels, bridges and railways that transport us. It is considered as a key element in the social and economic well being for the human being.

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Nowadays, for the concrete production, the majority of the commonly used cement is ordinary Portland cement (OPC). For these, the cost of cement is continuously rising and natural resources are reducing (such as clinker). Cement acts as the main ingredient for the production of concrete. The demand of cement is increasing day by day for the mentioned reasons. During the cement production, clinker is burnt at about 1450°C (Neville, 1995) consequently huge amount of CO_2 is emitted to the atmosphere. Hence temperature of the globe is increasing which is one of the reasons for climate change. About 7% of world's CO_2 is produced for the manufacturing of cement. In consequence, global warming is increasing continuously (Mehta, 1999). To solve these, researches in cement and concrete technology have been concentrated to use the WM as a potential alternative in the construction industry.

During recent decades, about thousands of tons of palm oil fuel ash (POFA) are produced yearly by operation of 200 palm oil mills in Malaysia and most of these POFA are normally disposed for landfill without any commercial return (Awal, 1997). Over half of the world's total palm oil is produced from the oil palm industry in Malaysia; the country has a plan to grow further with the world increase in vegetable oil demand. Though, environmental pollution is also increased for this palm oil sector - annually 2.6 million tonnes of solid waste is produced in the form of oil palm shells (Basri, 1999). The production of oil palm is increasing according to the demand; as a result the production of POFA is rising every year. Now, POFA has become an important environmental disposal issue. Malaysian government desires to focus for assigning more hectares of land for disposal of these huge amounts of waste; and financial losses are also involved for transporting as well as handling purposes of these wastes. Similar problem has been shown for the production of slag - a byproduct from the still mills, rice husk ash - a waste from rice processing mills, and saw dust ash/ash from timber. However, dumping issues of these waste and environment sustainability can be ensured by proper utilization or recycling of these materials. Recently, many research have been performed in cement and concrete technology for the use of biogenic wastes - POFA and rice husk ash (Awal, 1997; Basri, 1999; Saraswathy, 2007) sawdust ash (Elinwa, 2002) and bagasse ash (Chusilp, 2009) - as constituents in concrete. On the other hand, slag and fly ash have been used in cement and concrete as a supplement from many years, more than a century. All of these wastes contained a high amount of silicon dioxide in amorphous form and as a result they could be used as pozzolanic materials. Besides, strength and durability properties of concrete containing these ashes are improved significantly, as stated in different published literatures. Therefore, mentioned problems regarding cement production, WM and environmental pollution can be controlled or minimized with proper consumption of these wastes during cement manufacturing and concrete production which will meet the SC requirements. These wastes are abundantly available in Malaysia, thus, there is a great opportunity of producing SC from Malaysia's industrial by-products and biogenic wastes and today it is an important issue for the sustainable development that needs to be addressed.

Sustainability and Sustainable Concrete:

Today, sustainability is a key issue for the global concrete industry. Achieving sustainability has become more and more important question all over the world during the last decade. It is well known that sustain means to support or to maintain a process going, and the objective of sustainability is that life on the universe can be sustained for the projected future. Environment, economy, and society are the components of sustainability. At the present time, the environment is probably the most important component, and an engineer or architect exercises sustainability to reduce negative impact on the environment. Thus, the word sustainable tends to be identical with environmentally sound or friendly and green (Leslie). Large amounts of low cost building materials (portland cement concrete) is required for the construction of infrastructure due to rapidly industrializing world and this trends will be continued. The unlimited use of natural resources and huge amounts of environmental pollution is a principal caution for the preservation of the life-sustaining environment on the globe. Why the problem of sustainable industrial development has recently considered enormously significant? A difficult question that we have to identify how a sustainable development will be executed (Mehta, 1999). The various related concerns which lead us to the way of sustainable development that are mentioned below (Meyer, 2002):

- Previous mistakes could be cured by purifying the polluted water and soil.
- Reducing the global warming by neglecting the contamination of air, water and soil, as well as CO_2 emission.
- Balancing between consumption and generation of natural resources (material or energy).
- Searching a equilibrium between economic development and preservation of the environment (upgrading social life and the living standard by avoiding the disturbance of environment as much as possible).

However, for developing sustainability and sustainable concrete, engineers who are related to the concrete construction have to perform active responsibility in this area. They have professional duty to inform and teach clients, the public and fellow engineers about: the current building codes and laws, the long term benefits from using new environmentally-friendly technology and higher quality, durable designs. And they also take the following special responsibility to develop a world view in problem solving which considers the effects of infrastructure decisions on the earth and on all living things (Fredrik, 1999): (i) for the conservation and preservation of present resources, engineers should to be aware and responsible (ii) environmentally friendly technology could be implemented by their direct participation in order to execute a more sustainable future; and, (iii) they must apply a valuable leadership in these domain.

Concrete is one of the most widely used artificial construction material and its manufacturing process requires large amounts of raw materials (cement, sand, aggregates, and water). As a result, this concrete construction can make significant negative impacts over the environment. The SC is associated with reduction of the amount of polluting and CO_2 gases emitted during the concrete production, use of WM in more efficient way, development of low-energy, long-lasting, flexible buildings and structures exploiting the thermal mass of concrete in a structure to reduce energy demand (Sustainable Concrete, 2011). Two main actions that meet the needs for sustainable construction development are: a sensible use of natural resources that can be achieved by the use of by-products and reusable materials, and a lower environmental impact that will be gained through reduced carbon dioxide emission and reduced natural resources extraction from quarries (Moriconi,). For performing the goal of sustainable development, one of the solutions suggests the possibility of using the industrial by-products of thermoelectric plants (Carlos, 2001). By designing for durability as well as undertaking life cycle analyses of construction projects, the cement replacement materials such as fly ash in concrete, a better sustainable way is possible to direct the construction industry, and particularly the concrete production (Fredrik, 1999). Therefore, the other industrial byproduct (slag) and the biogenic waste (POFA, RHA, and AFT) that are available in Malaysia will make an important and active role in this regards.

Pozzolanic Activity of Waste Materials:

Pozzolans are such fine materials, with containing silica and/or alumina, that they do not exhibit any cementing properties of their own; in the presence of calcium oxide (CaO) or calcium hydroxide ($Ca(OH_2)$), silica and alumina in the pozzolans react and form cementitious materials (ASTM, 2001). POFA contains the silica oxide that can react with calcium hydroxide ($Ca(OH)_2$) generated from the hydration process; and the pozzolanic reactions produce more calcium silicate hydrate (C-S-H) gel compound as well as reducing the amount of calcium hydroxide (Eldagal, 2008). POFA is an agrowaste ash that contains a large amount of silicon dioxide and has high potential to be used as a cement replacement. For producing high-strength concrete, POFA can be used as a pozzolanic material; it improves the durability, reduces cost due to less use of cement. It will also be beneficial for the environment with respect to reducing the waste disposal volume of landfills (Tangchirapat, 2009). The siliceous glass is the primary contributor from the fly ash to pozzolanic reaction in concrete since it is the amorphous silica that combines with free lime and water from calcium silicate hydrate (C-S-H), the binder in concrete (ACI, 1996). For the same chemical composition, the activity of fly ash is greater due to the higher the proportion of vitreous matter (Fu, 2002). The reaction between RHA and $Ca(OH)_2$ solution was investigated by Yu *et al.* (1999) and they suggested that in the presence of water, a kind of fine C-S-H gel is formed after their reaction. The same opinion was found in a study of Feng *et al.* (2004). Amorphous silica could be found in some pozzolanic materials which react with lime more eagerly than those of crystalline form (Lin, 2003). As a result of this pozzolanic characteristic, RHA is an extremely reactive pozzolanic material and it is suitable to use in lime-pozzolan mixes and Portland cement as a supplement. It is well known that the utilization of mineral admixtures (such as FA, slag, RHA, POFA) has a positive effect on the quality of the concrete by binding the $Ca(OH)_2$ (Papadakis, 2002; Mehta, 1983). Therefore, due to their pozzolanic action all these waste materials could be used in concrete as replacement of cement. In consequence, they could execute a vital task for the SC construction.

Necessity and Opportunity of SC Using WM:

Since global warming has known as the most crucial environmental issue at present time and sustainability is becoming an important issue of economic and political debates, and for the next developments in the concrete industry will not be the new types of concrete - produced with expensive materials and special methods - but low cost and highly durable concrete mixtures containing largest possible amounts of industrial and agricultural waste/byproducts that are suitable for supplementary use of portland cement, virgin aggregate, and drinking water (Mehta, 2004).

Besides, huge energy is required for burning of clinker during the production of cement, for these a large amount of CO_2 is produced and released to the atmosphere. Approximately, one ton of CO_2, a greenhouse gas, is delivered into the atmosphere for each ton of cement production. Worldwide, the cement industry is responsible for about 1.4 billion tons in 1995, which caused the emission of as much CO_2 gas as 300 million automobiles - statistically for almost 7% of the total world production of CO_2 (Malhotra, 2000). Hence environmental pollution and global warming is increasing continuously and, natural resources and energies are being reducing day by day. On the other hand, huge amount of biogenic wastes (POFA, RHA, AFT) are being produced in the developing countries, Malaysia is the best example. Industrial by-products (slag, FA) are generated from the developed as well as developing countries. In fact, in spite of their technical and financial benefits, till now there is no potential example of using these ashes, they are only used as landfill purposes. Consequently, environmental pollution is observed, huge land area is covered and become useless, and contamination of soil is happened. Moreover, addition of WM in cement could reduce the releasing rate of CO_2 to the atmosphere. The embodied CO_2 emission feature along with WM and without its contribution to cement production has been presented in Table 1. It can easily be understood that, due to incorporation of waste material into cement, the embodied CO_2 emission is reduced significantly. For example, with addition of 50% slag, embodied CO_2 emission is reduced by 56 kg/ton (36.6%). This feature has a similar trend for the total CO_2 emission into the atmosphere during the cement manufacturing. For 50% slag addition, total CO_2 emission is reduced to 53.3%: for CEM I, CO_2 emission is 1011 kg/ton but for 50% slag, this value is dropped down to 539 kg/ton. Besides, for the case of energy saving/conservation, consumption of WM is a vital factor that can easily be observed from a statistics of Fig. 1.

It is seen from this figure that, for CEM I total energy requirement is 1587 kWh/ton. This data is 1206, 938 and 602 kWh/ton for the utilization of slag by 30, 50 and 75% respectively. These imply that for 50% slag replacement, energy requirement is reduced to 59.1% as refer to CEM I (100%), or alternatively, 40.9% energy can be saved for the use of 50% slag. This figure is much superior for the 75% slag replacement (i.e., only 37.9% energy required with reference to CEM I or 62.1% energy would be saved). Thus, evidently it can be said that utilization of WM in cement production in Malaysia would be a potential step for restriction of CO_2 emission as well as reservation of energy.

WM could be used as effective construction materials and have the ability to satisfy the design specifications provided that it would be processed properly. In fact, many by-products and solid WM can be used in concrete mixtures as replacement of aggregates or cement, depending on their chemical and physical characteristics. The capacity of concrete for incorporating these secondary raw materials is very wide and the main limit is their availability (Moriconi). FA is a byproduct of coal combustion that is collected in smoke stacks; it is a lower cost cementitious substance that has been used for about or more than a century as a better environmentally benign substitute for some of the Portland cement content in concrete; it saves money, has some superior performance characteristics, and in terms of sustainability, fly ash preserves raw materials and reduces CO_2 emissions (Fly Ash, 2011). There are unlimited supply of good quality fly ash worldwide, and these ashes have been used in concrete as supplement of cement in different study: new concrete technology such as high-volume fly ash concrete has been developed, superplasticizers and supplementary cementing materials used in combined, leading to economical high-performance, crack-resistant concrete with improved durability (Mehta, 1999; Malhotra, 1986; Malhotra, 2002). Therefore, this is the optimum time of producing SC using WM as concrete ingredients, as a supplement of cement or direct incorporation into concrete. This process would be useful and meaningful simultaneously for the following multiple advantages: minimization of waste disposal, environmental pollution, saving raw materials as well as energy, and reduction of CO_2 emissions. There is great opportunity to perform this step in Malaysia and it could be successfully implemented here because the country produces a large amount of biogenic and industrial wastes.

Benefits of Using Waste Material in Concrete:

Recently, the use of supplementary cementing materials from other sources has become significant for technical, environmental and economic reasons. Reutilization of industrial by-products (slag, fly ash, ash from timber, agricultural waste-RHA, POFA, ceramic waste, kiln dusts, sludge, concrete demolition waste, incinerator ash, and others) and post-consumer waste (glass, plastic, tires, steel, fibres) as supplementary material, reinforcing agents, or as aggregates could have a beneficial effect on concrete's total embodied energy as well as on long-term performance and durability. A concrete containing WM (fly ash, slag, POFA, RHA) is an example of sustainable construction development which is feasible with satisfactory performance, in terms of both safety and serviceability of structures, at lower costs and with environmental advantages over ordinary concrete, as stated in different literatures.

Moreover, when recycled materials appropriately used in concrete, some important properties of the hardened concrete such as ductility and durability can be improved (Moriconi). There are more advantages of using WM in cement and concrete as mentioned below:

- POFA can be used as pozzolans to replace part of Portland cement in making mortar with relatively high strength and good resistance to chloride penetration (Chindaprasirt, 2008).
- Utilization of POFA in concrete could reduce the cost of concrete production due to less cement use; disposal problem can be minimized (Rukzon, 2009; Tangchirapat, 2007).
- Incorporation of RHA improves compressive strength (Safiuddin, 2010) flexural strengths of concrete (Coutinho, 2002; Ismaila, 1996) and split tensile strength (Habeeb, 2009; Sensale, 2006).
- RHA shows better durability of concrete (Coutinho, 2002).
- Addition of RHA improves resistance to sulfate attack (Chatveera, 2009; Sakr, 2006; Chindaprasirta, 2007).
- Strength increases (Chatveera, 2009) with increasing amount of fly ash up to an optimum value of 40% of cement (Oner, 2005).
- FA can be used as a low or zero-cost raw material, the conservation of natural resources, and the elimination of waste (Ferreira, 2003).
- FA reduces the rate of penetration of chloride ions into concrete (Bijen, 1996).

Concluding Remarks:

There are huge amounts of industrial by-products (slag) and biogenic wastes (POFA, RHA, AFT) produced from the steel mills and agricultural sector, respectively, in Malaysia. Having the technical and financial benefits, most of these wastes are, still now, dump into environment without any potential reuse. For the disposal purpose, a lot of money is spent to transport these wastes; besides, huge land area becomes ineffective and the fertility of land is reduced day by day. In addition, a huge amount of air pollution and natural resources consumption are done by the concrete industry. So, cement and concrete itself have to bear a special responsibility to contribute towards sustainable development. It can do so by pursuing an alternative way for cement production technologies that are less energy intensive and cause minor air pollution. Since such technologies will not be available in the foreseeable future, the better realistic approach is to reduce/avoid the dependency on Portland cement. It can be solved primarily by increased use of supplementary cementitious materials, especially waste materials. Thus, all of these mentioned problems can be settled or minimized by effective consumption of these wastes through the production of cement or concrete.

Due to their large amount of silica content and excellent pozzolanic property, these wastes could be used as a supplement of cement in concrete manufacturing. Indeed, inclusion of these wastes either in cement or in concrete production not only saves the cement material but also ensures the quality and durability of concrete. This observable fact will make a vital role and will have the practical view of SC production. Moreover, a valuable cement and energy conservation attempt could be executed by proper utilization of wastes during the production of cement or concrete that can be meaningful for the SC production at the present demand of concrete society in Malaysia.

The present essential issues - SC production, waste disposal solution, and global warming - could be attained by proper consumption of wastes in cement or concrete in Malaysia. The utilization of waste for producing SC is logical, economic and energy saving step for making a safe, hygienic, and comfortable planet for the present and future human society.

Table 1: Embodied CO_2 study, 2007 and CO_2 emission for cement production.

Cement type		Embodied CO_2 (kg/ton)			Reference
CEM I		153			Embodied CO_2 study, 2007
CEM IIB-V (30% fly ash)		130			
CEM IIIA (50% slag, GGBS)		97			
		Total emission of CO_2			
	Amount kg/ton (%)	Decarbonation: 0.55 t_{CO2}/t_{Cl}	Electric Energy: 651g/kWh	Thermal Energy: 331g/kWh	
CEM I	1011(100)	54.4	14.3	31.3	Ehrenberg, 1997
CEM IIB-S (30% slag)	730 (72.2)	52.8	16.9	30.4	
CEM III/A (50% slag, GGBS)	539 (53.3)	51.0	19.6	29.4	
CEM III/B (75% slag, GGBS)	300 (29.7)	45.8	27.8	26.4	

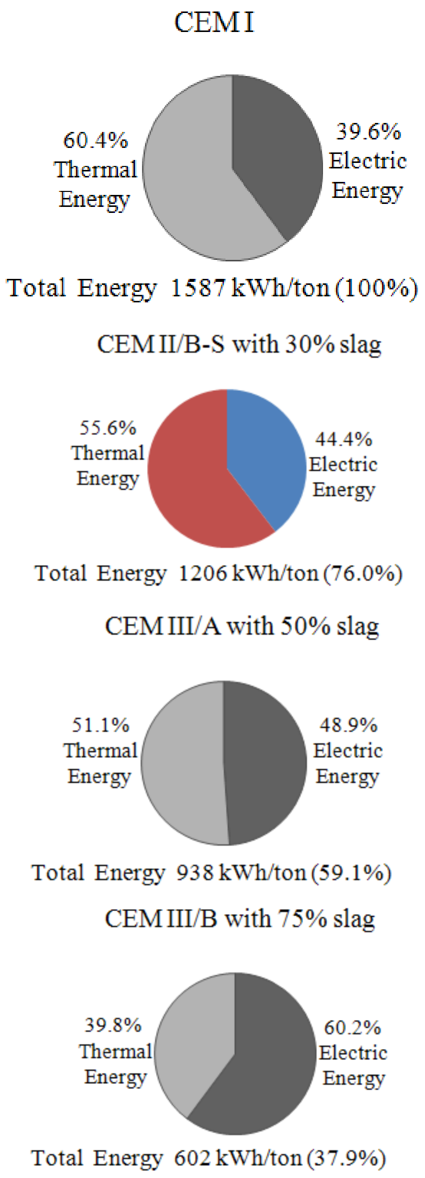

Fig. 1: Energy consumption for cement production (Ehrenberg, 1997).

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