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Waste Materials in Malaysia for Development of Sustainable Concrete: A Review

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ABSTRACT:

This paper discusses on the availability of waste materials in Malaysia and their potential use as building materials in the local construction industry. The waste materials discussed include fly ash (FA), oil palm kernel shell (OPKS), rice husk ash (RHA), palm oil fuel ash (POFA), quarry dust (QD), recycled ceramic, and recycled coarse aggregate (RCA). The past research on the use of these materials shows that structural grade concrete can be produced. . Similarly, the use of FA, RHA and POFA as partial replacement of cement or additional cementitious materials can be used to produce low to medium strength concrete as well as high strength concrete (HSC). In addition, lightweight OPKS enables it in the production of lightweight concrete (LWC). Recent research on the use of FA, RHA and palm oil clinker (POC) to produce geopolymer concrete is also producing results. In general, the utilization of these waste materials in concrete leads to sustainable concrete and reduces environmental impact from the manufacture of concrete using conventional materials such as crushed granite and cement

1 INTRODUCTION

Researches on incorporating industrial and construction waste products into potential construction material to produce sustainable concrete have been on the rise since 1980. Fly ash (FA), oil palm kernel shell (OPKS), rice husk ash (RHA), palm oil fuel ash (POFA), quarry dust, recycled ceramic and recycled concrete aggregates (RCA) are the examples of industrial and construction & demolition wastes. The researchers focused on using OPKS, recycled ceramic and RCA as possible replacement for conventional crushed granite aggregate as coarse aggregate; however RHA, FA, and POFA have been investigated as supplementary mineral admixtures in concrete. Quarry dust has been used as a replacement material for fine aggregates.Sustainability has become more and more imperative all over the world, especially in the production of concrete. Utilization of these materials paves way for sustainable concrete which contributes to reduction of environmental pollution as the production of conventional construction materials such as cement and normal coarse aggregates could be reduced.

2 WASTE MATERIALS AS COARSE AGGREGATES

2.1 Oil palm kernel shell (OPKS)

From Table 1, an average 2.2-2.4 million tonnes of OPKS is produced annually (MPOB, 2011). In the early practice, oil palm wastes include OPKS and POFA were disposed by uncontrolled dumping which eventually caused environmental pollution. Utilization of these wastes into potential materials in the production of concrete helps to reduce pollution as well as reduces the requirements to monitor the dumping sites.

Table 1: Generation of OPKS, oil palm kernel and POFA in Malaysia (MPOB, 2011).

Materials	Waste generated (million tonnes)				
	2007	2008	2009	2010	Jan-June 2011
OPKS	2.2	2.4	2.3	2.2	1.3
Oil palm kernel (fruit)	4.1	4.6	4.5	4.3	2.6
POFA	0.06	0.06	0.06	0.06	0.04

Abdullah (1984) was the first to incorporate OPKS into concrete and he showed that LWC using OPKS as lightweight aggregates (LWA) can be produced. Mannan & Ganapathy (2001) reported that the long term behaviour of OPKS concrete is very similar to the control concrete from crushed stone, which confirmed that no retrogression in strength under different curing conditions. However medium compressive strength of 20 – 24 MPa was reported. Mannan & Ganapathy (2001) reported that bonds between OPS and cement paste were not as strong as that of control concrete because of the smoothness of OPS surface. Okafor (1988) suggested that the use of OPKS cannot produce concrete with compressive strength above 30 MPa and OPKS is suitable for concrete grade 25 and below compared to conventional coarse aggregates. However in latter researches, Alengaram *et al*. (2010) increased the 28-days compressive strength to 36-38 MPa by incorporating silica fume while Shafigh *et al*. (2011) developed a new method to produce high strength OPKS concrete of 28-days compressive strength of 53MPa by using crushed OPKS.

Utilization of OPKS concrete as structural LWC was investigated as density reduction of 18% and 20% was reported by Teo *et al*. (2007) and Alengaram *et al*. (2010) respectively, compared to normal weight concrete (NWC). The use of lightweight concrete (LWC) permits greater design flexibility and substantial cost savings, reduce dead load, improved cyclic loading structural response, longer spans, better fire ratings, thinner sections, smaller size structural members, less reinforcing steel and lower the foundation costs (Alengaram *et al*. 2010). In terms of other mechanical properties, Alengaram *et al*. (2010) showed splitting tensile strength and modulus of rupture of OPKS concrete (approximately 6% and 10% respectively of compressive strength) are close to NWC (approximately 8% and 13% respectively). However modulus of elasticity of OPKS concrete is only 40% of NWC. From the durability point of view, the water absorption and water permeability of OPKS concrete were also comparable to other LWC containing pumice and expanded polystyrene (Teo *et al*., 2007). Although OPS aggregates are porous in nature, the resulting OPKS concrete was reasonably impermeable.

2.2 Recycled ceramic

In ceramic industry, about 15-30% production goes to waste and the ceramic waste is durable, hard and highly resistant to biological, chemical and physical degradation forces. Therefore there is a pressure on ceramic industry to find a solution for the ceramic waste disposal (Abdullah *et al*., 2006). Abdullah *et al*. (2006) reported the properties of Concrete Ceramics Waste Slab (CCWS) which replaced crushed stone with recycled ceramic are not significantly different from conventional concrete. In their study, the recycled ceramics are crushed to small pieces by a hammer and the small pieces are then fed into vibrator to be sieved in order to get the required 14-20mm size. The reported compressive strength of CCWS varies in the range of 15-30 MPa. Compared to conventional concrete, CCWS has lower density. Abdullah *et al*. (2006) suggested that CCWS can be used as landscape product such as table, chair, drain cover and others.

2.3 Recycled concrete aggregate (RCA)

Extraction of natural aggregates such as granite has created ecological imbalance and it is unsustainable. Utilization of recycled coarse aggregate (RCA) is one of the methods to reduce the dependence to granite stones. RCA exhibits lower bulk density and saturated surface dry density. The higher porosity of the RCA compared to normal aggregate is due to the higher content of adhered mortar responsible for its low resistance towards mechanical and chemical actions. In addition, it exhibits higher water absorption of values between 4-9.5% as compared to that of the natural aggregate (Kwan *et al*., 2011).

Tangchirapat *et al*. (2008) showed concrete with RCA as 100% replacement of coarse aggregate exhibits similar mechanical properties compared to conventional concrete. A comprehensive study from Adnan *et al*. (2007) revealed that increase in w/c ratio and RCA content decreases the compressive strength of RCA concrete. The compressive strength and water permeability of RCA concrete was further enhanced by incorporating micronised biomass silica made from controlled burning of rice husk (Adnan *et al*., 2010)

3 WASTE MATERIALS AS CEMENTITIOUS MATERIALS

3.1 Fly Ash (FA)

By 2010, about 40% of electricity in Malaysia is generated by pulverized coal firing, which consumes approximately 11 million tonne of coal annually and the use of coal burning in thermal power plants results in production of fly ash (FA) of approximately 3 million tonnes per annum. It is estimated in future production of FA is likely to be doubled and there is problem of disposing this waste as it causes environmental and storage problems. Studies on FA as cementitious material have been well-established by many researchers. Study from Poon *et al*. (2000) showed that high strength concrete (HSC) with a 28-day compressive strength of 80 MPa could be obtained with a water-to-binder (w/b) ratio of 0.24, with a FA content of 45%. Another study from Jatrapitakkul *et al*. (2004) showed with a FA content 25%, the 28-day compressive strength of 82.5MPa could be obtained.

3.2 Palm oil fuel ash (POFA)

Palm oil fuel ash (POFA) is a reactive pozzolanic material with high potential for use as a partial replacement for cement in concrete. The compressive strength of concrete containing POFA depends on the fineness of the POFA and the amount of cement replacement (Tangchirapat et al., 2009). For every 100 tonnes of fresh fruit bunches processed, approximate 20 tonnes of nut shells, 7 tonnes of fibers, and 25 tonnes of empty bunches are discharged from the mill. Currently the OPKS and fiber are used extensively as fuel for the production of steam in the palm oil mills. After combustion in the steam boiler, approximately 5% of ash is being produced (Tay & Show, 1995). From table 1, 0.06 million tonnes of POFA is produced every year in malaysia and these POFA can be used as cementitious material in concrete. Study of Tay & Show (1995) revealed that with up to 10% ash content in the cement, the concrete exhibits insignificant strength reduction at the age of 1 year. Hence they concluded that POFA can be potential material for blending with Portland Cement in small amount. In latter research from Tangchirapat et al. (2009), partial replacement of Portland Cement (10-30%) was study by using ground fine POFA. From their results, concrete with 20% replacement by POFA shows a 90-day compressive strength as high as 70MPa. Other advantages of POFA in high strength concrete are reduction of water permeability, better sulphate resistance, smaller degree of expansion and loss in compressive strength.

3.3 Rice husk ash (RHA)

Referring to Table 2, paddy of 2.4-2.7 million tonnes are generated per year in Malaysia. According to Mutadhi & Kothandaraman (2010), most of the husk from the milling is either burnt or dumped as waste in open fields and a small amount is used for fuel. Paddy on an average consists of 20-22% husks, therefore approximately 0.52-0.59 million tonnes per annum of RHA are produced in Malaysia. RHA is used as a highly reactive pozzolanic material in concrete production and the ash properties vary due to the differences in incinerating conditions, rate of heating, geographic location and fineness (Hwang *et al*., 2011). Mutadhi & Kothandaraman (2010) reported their finding on optimum incineration condition is 500°C and 120 minutes grinding time. In addition, most of the mortar specimens with 10% replacement of cement by RHA attained higher strength than the reference mix (without RHA).

Table 2: Generation of paddy and RHA in Malaysia (Malaysian Department of Agricultural, DOA, 2011).

	Amount generated per year (million tonnes)				
	2007	2008	2009	2010	2011 (estimation from DOA)
Paddy	2.4	2.4	2.5	2.5	2.7
RHA	0.52	0.52	0.55	0.56	0.59

Hwang *et al*. (2011) showed that the compressive strength of concretes with up to 20% ground RHA added attain higher values (approximate 60MPa) compared to that control concrete after 28 days (56MPa). It is also showed that after 14 days of curing, the electrical resistance of all RHA concrete becomes higher than that of control concrete. Kishore *et al*. (2011) also presented their results for partial replacement of cement by RHA (0 – 15%) in grade 50 high strength concrete. From Table 3, as replacement of cement by RHA increases, decrease in mechanical properties includes compressive strength, splitting tensile strength, flexural strength and modulus of elasticity is observed. In addition, the increase in RHA results in decreasing workability.

Table 3: 28-day mechanical properties of high strength RHA concrete (Kishore *et al*., 2011)

RHA (%)	28-day Mechanical properties (MPa)			
	Compressive strength	Splitting tensile strength	Flexural strength	Modulus of elasticity
0	59.37	4.19	5.36	50680
5	56.40	4.60	4.87	47230
10	53.43	4.26	4.76	43520
15	50.46	4.19	4.72	38940

Several waste materials containing silica and alumina sources like fly ash (FA) and RHA could be used to produce geopolymer because of their suitable chemical composition along with favorable size and shape. Geopolymer has its advantage of independent on cement usage and researches on geopolymer are gaining concern due to this reason. Nazari *et al*.(2012) had reported the applicability of FA, RHA and palm oil clinker (POC) in producing geopolymer.

4 WASTE MATERIALS AS FINE AGGREGATES

4.1 Quarry dust

Quarry dust (QD) is crushed dust obtained from stone boulders in stone crushers during the production of coarse aggregates. The quarry dust consists of excess fines and is dumped in open fields that cause environmental pollution. Quarry dust has been used successfully in concrete, pavement construction, and in controlled low-strength materials (CLSM) (Naganathan *et al*., 2012). From the study of Naganathan *et al*. (2012), the addition of quarry dust does not affect the setting time but it reduces the water demand for constant flow consistency and increase the fresh density and hardened density of concrete. It is concluded that there is potential for the use of industrial waste incineration bottom ash and quarry dust in CLSM. Addition of quarry dust enhances the performance of the mixtures. While Raman *et al*. (2011) reported that substitution of quarry dust into the HSC mixes resulted in a slight decrease in the compressive strength. However the negative effect due to quarry dust substitution can be compensated with the inclusion of RHA into the mix.

5 CONCLUSIONS

The following conclusions can be drawn by using the waste materials in producing sustainable concrete that might help to reduce environmental pollution and dependence on natural resources for concrete:

1. OPKS is suitable as replacement for natural granite as coarse aggregate to produce high strength LWC with 28-days compressive strength up to 53 MPa.
2. Recycled ceramic can be used as coarse aggregate to produce CCWS with compressive strength 15-30 MPa.
3. RCA is applicable as replacement of natural coarse aggregates.
4. FA is a well-established cementitious material to be incorporated in HSC.
5. Concrete containing low percentage of POFA or RHA experienced insignificant reduction of compressive strength and can be used in producing HSC.
6. Both FA and RHA can be used in the production of geopolymer concrete.
7. Partial replacement of fine aggregate by QD is feasible as it provides better performance in CLSM and causes slight decrease of compressive strength in HSC.

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