USAGEOF PALMOIL INDUSTRIAL WASTES AS CONSTRUCTION MATERIALS - A REVIEW

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Abstract- Palm oil industry produces millions of tonnes of industrial wastes and these wastes create huge storage and environmental problems. In order to solve these problems various research works have been performed for past decades. The commonly available wastes are Oil palm shells (OPS), Palm oil clinker (POC) and Palm oil fuel ash (POFA). These materials have already acquired well recognition as alternate of conventional construction materials. OPS has been used as coarse aggregate and compressive strength was found up to 56 MPa for 56-day. It is said that 30 grade Oil Palm shell concrete (OPSC) is possible without adding any cementitious materials. The maximum modulus of elasticity for OPSC was found 18.6 GPa. The Oil palm shell concrete (OPSC) are used for drain blocks, road-kerbs and house where the palm oil factories are available. In case of superstructure like beams and slab are also produced by utilizing OPS. POC maintained the desired range of strength and density of structural lightweight concrete. The mechanical properties of POC has been evaluated through the research work. Their main aftermath is that the POC has been categorized as a structural lightweight concrete in accordance with the requirements of the ASTM: C330 and BS8110. Many experimental works have been performed to establish POFA as a substituting binding material in replace of Ordinary Portland cement (OPC). Throughout the research it has been showed that up to 20% of cement by mass can be replaced by POFA. POFA is one of the most enriched pozzolanic materials. The main purpose of this review is to discuss the usage and opportunity of the palm oil industrial wastes as construction materials following the previous experimental research work.

Keywords- Construction Materials, Oil Palm Shells (OPS), Palm Oil Fuel Ash (POFA), Palm Oil Clinker (POC).

I. INTRODUCTION

CONCRETE is the most usable materials now a days, right after water in this world.It is accounted that the demand for concrete is predicted to increase approximately 18 billion tonne a year by 2050 [3]. It has been reported that the concrete industry will consume 8– 12 billion tonnes of natural aggregates annually after the year 2010[5].As is widely acknowledged, the production of Ordinary Portland Cement (OPC) has a huge environmental impact due to the large amount of greenhouse gas released into the atmosphere. The production of 1tonne of cement contributes 1 tonne of CO_2 to the atmosphere, together with minor amount of Methane, Nitrons oxides and Flourine. Thus, the CO_2 emission due to the production of OPC has been reported to be about 13,500 million tonne, which accounts for 7% of greenhouse gases annually worldwide [8]. Moreover, other emitted gases, such as SO_3 and NOx from the manufacture of cement cause acid rain and the greenhouse effect, which have a grave impact on our environment. The production of 1tonne of OPC normally requires about 1.5 tonnes of raw materials, such as limestone and sand; in addition, 1tonne of OPC clinker consumes ahuge amount of energy in the order of 1700–1800 MJ [9]. Concrete made of OPC has a durability problem, such as sulphateattack, steel corrosion, aggregate-alkali reaction and fireresistance.

The strength of ordinary concrete starts to decrease at a temperature of around 400° C. Conversely, it has been told that in near future the production of Ordinary Portland Cement (OPC) will cause 10% of total anthropogenic CO_2 emissions throughout the world [11] and the level of CO_2 may increase in the range of 380 ppm to 800 ppm by the end of the century[9].In previous past few decades, it was noticed that the price of raw materials has been increasing and a continuous reduction of natural resources alarmingly. On the other hand, the recycling or utilization of solid wastes generated frommost agro-based industries and manufacturing industries isvery rewarding. The anxiety about enormous waste production,resource preservation, and material cost has focused attentionfor the reuse of solid waste. Material recovery from the conversion of agricultural wastes and industrial wastesinto useful materials has not only environmental gains, butmay also preserve natural resources. So, researchers have been giving efforts in establishing the agricultural and industrial wastes as alternative construction materials, considering the economical and environmental negative effect of normal conventional constructional materials.

In this study, the new opportunity and previous research findings of palm oil wastes as alternative construction materials will be focused.

II. PALM OIL INDUSTRIAL WASTES

A.Oil Palm Shells (OPS)

The oil palm industry is one of the most important Palm Oil industriesin certain countries, such as

Malaysia, Indonesia, Thailand andNigeria. Malaysia and Indonesia are, respectively, the world's largestand next largest palm oil producing countries.For instance, in Malaysia, Indonesia andThailand, the annual production of solid waste from the palm oilindustry is 47, 40 and 3.5 million tons, respectively. Inaddition, over 8 million tons of oil palm shell is produced by thesecountries, annually[12]. Fig. 1 shows the global scale of world palm oil production between 1996 and 2000 [13].

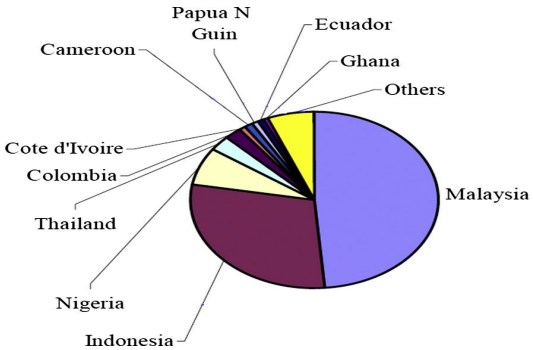

Fig. 1 World palm oil production 1996–2000[13].

OPS are a waste product from the extraction of oil from the oil palm tree. The oil palm tree, being in the same genera as the coconut palm tree, shares many of its features. Its scientific name is Elaeisguineensis. OPS are the hard endocarp that surrounds the palm kernel. Fig. 2indicates the uncrushed and crushed OPS.



Fig. 2Uncrushed and crushed palm oil shells[14].

The color of oil palm shell (OPS) ranges from dark grey toblack. Depending on the breaking pattern of the nut, the shape ofthe shells differs in a range from angular to polygonal.

TABLE *I*shows the characteristics of OPS. As can be seen in this table, OPS isapproximately 60% lighter than conventional coarse aggregates.The density of OPS is within the range of most typical lightweightaggregates [15, 16]. One of the attractive characteristics of oil palmshells is its significant low Los Angeles abrasion value, which isapproximately 80% lower than conventional coarse aggregates[17]. This characteristic shows that OPS aggregates have goodresistance to wear. In addition, because of the much lower impactand crushing values of OPS aggregates, these aggregates have goodabsorbance to shock [18]. The surfaces of the shells for both concaveand convex faces are fairly smooth, while the broken edge isrough and spiky.

The use of OPS as a lightweight aggregate for producing lightweight concrete was explored as early as 1984 by Abdullah [19] in Malaysia and by Okafor [15] in Nigeria. In most cases,

TABLE I
PROPERTIES OF OIL PALM SHELLS AS CONSTRUCTION MATERIALS[14]

Properties	Oil Palm Shells
Specific gravity	1.17-1.37
Bulk density (uncompacted) (kg/m^3)	510-550
Void ratio (uncompacted) (%)	63
Void ratio (compacted) (%)	57
24 h water absorption (%)	21-33
Aggregate impact value (%)	4-8
Aggregate crushing value (%)	5-10
Los Angeles abrasion value (%)	3-5
Flakiness index (%)	65
Shell thickness (mm)	2-8
Thermal conductivity (W/mc)	0.19
Loss on ignition (%)	98-100

it has beenshown that the compressive strength of OPS lightweight concrete,with and without cementitious materials, is within the typicalcompressive strength for structural lightweight concrete (20–35 MPa) with a density of about 20–25% lower than normal weightconcrete (NWC) [16, 17, 20-23]. However, recent studies haveshown the possibility of producing high strength OPS lightweightconcrete of up to about 53 and 56 MPa for 28 and 56 days compressivestrength [24, 25]. Promoting the compressive strength of concreteand the ability to produce high strength concrete withaggregate, such as OPS, is very important because the compressivestrength of concrete plays a fundamental role in the design andconstruction of concrete structures [26], and, also, such potentialapplication of a waste material will encourage the constructionindustry to use this type of environmentally friendly concrete inactual projects. The techniques for producing high strength OPSconcrete have been explained in various published papers.

From the test results of previous studies it was concluded [27]that the mechanical properties of OPS concrete, such as splittingtensile strength, flexural strength and modulus of elasticity at thesame

compressive strength, are lower than other types oflightweight aggregate concretes made from artificial or natural lightweight aggregates.



Fig. 3Structures made of oil palm shell concrete: (a) footbridge and (b) low-cost house[14].

The durability properties of OPS structural lightweight concrete under different curing conditions were investigated by Teo et al.[28]. They reported that the durability properties of this concretewere comparable to that of other conventional lightweight concretes.The research concluded that proper curing is required forOPS concrete to achieve better durability. They recommended thatthe minimum duration of moist curing should be carried out continuouslyfor at least 7 days.

Ahmed and Sobuz[29] reported that the flexural behavior of beams made of oil palm shell shows very close agreement withthe theoretical results. Furthermore, the satisfactory shear behavior of oil palm shell concrete beams has also been reported[30, 31]. Alengaram et al. [32] reported that the overall flexuralbehavior of reinforced OPS concrete beams closely resembled thatof equivalent beams made with normal weight concrete.

For showing the potential use of oil palm shell (OPS) as aggregate for producing lightweight concrete in practice, two smallstructures were built at University Malaysia Sabah (UMS) [33].These structures comprised a small footbridge with a span of about2m (Fig. 3a) and a low-cost house with a floor area of about 59 m^3Fig. 3b). These structures are located near the coastal area, whichhas an annual rainfall of about 2500 mm, air temperature in therange of 23–32° C and relative humidity of 72–91%.

B. Palm Oil Clinker (POC)

Malaysia is the second largest palm oil producing country in the world and produces more than half of world's palm oil [34]. One of the agro-industrial by-product from the palm oil industry is palm oil clinker (POC). POC is produced through the incineration process of oil palm shell (OPS) and mesocarpfibre[35]. The huge production of POC is generally dumped to the landfill that causes ecological imbalance. The proper utilization of POC in the construction industry may promote the environmental sustainability. The low specific gravity and high aggregate crushing value have made the potentiality of usage of POC as an alternative source of aggregate which has not required any pre-treatment or modification [35] and this could lead to reduce the depletion of natural resources.TABLE IIand TABLE IIIshow the physical and chemical properties of coarse POC.

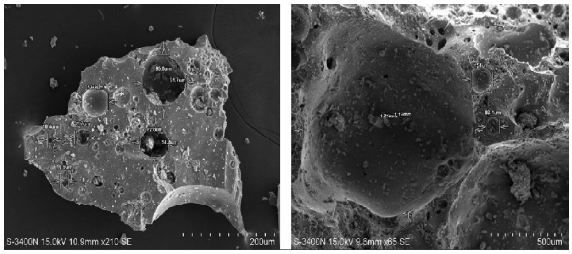

Fig. 4 Size of pores in POC clinker sand [34].

POC based lightweight aggregate (LWA) concrete (POCC), in terms of ductility, was reported as slightly lower ductile material than normal weight aggregate (NWA) concrete (NWAC). Ahmmad, R. et al. [34] found 1.26 and 1.54 times lower displacement and torsional ductility index of POCC than that of NWAC. Similarly, the modulus of elasticity, modulus of resilience, modulus of toughness and strain were reported to lower value; however the compressive strength of POCC was comparatively lean to that of NWAC [34].

Mohammed, B.S. et al. [36] reported that POCC concrete beams meet the maximum tolerable deflection criteria as suggested by BS8110. Kanadasan, J. and Abdul Razak, H. [35] proposed a mix design of POC for self-consolidated concrete which fulfilled the criteria as recommended by EFNARC (2005). Fig. 4andFig. 5 show the size of pores in POC clinker sand and physical appearance of POC, respectively. The rising porous condition and lack of goodbond formation between the POC aggregate play a vital role in lowering the Ultra Sonic Pulse velocity (UPV) and strength properties. At the highest POC replacement ratio, good strength and reduction in density can be achieved to produce satisfactorystructural efficiency. The endurance against resistivity for allPOC incorporated SCC was almost identical compared to that ofcontrol specimens and was well above the required minimumlevel[35].

TABLE II
PHYSICAL PROPERTIES OF COARSE POC [34, 35]

Properties	POC
Specific gravity	1.73-2.08
Moisture content (%)	1 ± 0.5
Water absorption (%)	3 ± 2
Aggregate crushing value (%)	56.44

Local mining sand and oil-palm-boiler clinker

(OPBC) lightweight sand were used as fine aggregates [37]. An increase in the OPBC sand in OPS concrete reduced the slump value. However, OPS concrete containing OPBC up to 37.5% still has a satisfactory slump value that can be adequately vibrated. Incorporating OPBC sand further reduces the density of OPS lightweight concrete. Compared to normal concrete, the density of OPS concrete containing 0% to 50% OPBC sand was 21% to 27% lower. The splitting tensile strength and flexural strength of OPS concrete was reduced by incorporating OPBC sand. The reduction in the flexural strength was more than for splitting tensile strength. In general, OPS concretes had about 20% lower splitting tensile strength compared to normal weight concrete at the same compressive strength. The modulus of elasticity of OPS concrete is reduced by incorporating OPBC sand. However, the reduction is not significant by incorporating OPBC sand up to 37.5% [37].

TABLE III
CHEMICAL PROPERTIES OF COARSE POC [34]

Chemical composition (%)	POC
SiO_2	59.63
Al_2O_3	3.7
Fe_2O_3	4.62
CaO	8.16
MgO	5.01
SO_3	0.73
Na_2O	0.32
P_2O_5	5.37
TiO_2	0.22

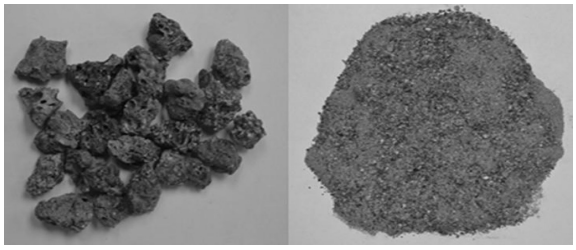

Fig. 5 POC coarse and POC fine [35].

Taking into account the situation of using cement instead of POC powder to supplement the additional paste volume that would be required for all the cases, would lead to a significantly huge amount of CO2 arising from the excessive cement requirement. As POC 100 required a substantially high paste volume due to the lower packing values, a rise of about 415 kg/m3 of cement was needed to generate the same quantity of paste required in comparison to only 341 kg/m^3 for POC powder. Hence, POC powder could stand as an alternative solution to reduce the discharge of dangerous CO2 into the environment. This recycling concept adapting 'zero' waste production would be advantageous to the building industry and would encourage a proper waste management system [35].

It was found that POC aggregate require three times lower energy consumption for preparation compared to conventionalaggregate. Overall, POC incorporation showed enhanced structural efficiency with a significant reductionin cost and energy usage. Furthermore, the sustainability of the construction industry can be conservedwith the introduction of POC as an alternative source for concreting work.

C. Palm Oil Fuel Ash (POFA)

Cement content still requires reduction despite the significant potential of existing mathematical and statistical methods. The most sensible solution is to replace large portions of cement with industrial products such as fly ash [38], silica fume [39], ground granulated blast-furnace slag [40], reject fly ash, recycled glass powder [41], and rice husk ash [42] as supplementary cementitious materials. A new supplementary cementitious material was used recently to address both environmental and economic concerns. The material is palm oil fuel ash (POFA) [43]. Generally, the large amount of residues like fibers, nutshells and empty fruit bunches is produced from palm oil mill which are burnt at temperatures of about 800–1000˚ C as fuels to provide steam for electricity generation in palm oil mills. After the burning process, an ash by-product is obtained, which is about 5% by weight of the residues, known as palm oil fuel ash (POFA). While the quantity of POFA is rising annually, its utilization is limited and basically disposed of as a waste in landfills without any profitable return. It can also cause environmental problems, health hazard and financial loss.High amounts of POFA are produced in Malaysia, Thailand, and Indonesia; these amounts are expected to increase annually [43, 44].

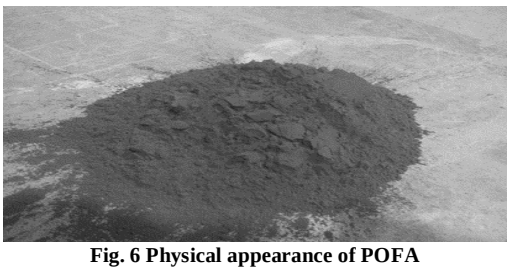

Fig. 6 Physical appearance of POFA

Many researchers have found that POFA has pozzolanic qualities and properties [45, 46]. A pozzolan is a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. POFA has a large content of SiO_2 which can potentially make it a favorable pozzolanic material. Fig. 6shows the physical appearance of POFA.

Pozzolans (trass) are natural rocks (e.g. tuff) of volcanic origin and composed of silica and alumina oxides but almost no lime. Therefore, they cannot develop hydraulic properties in the absence of hydrated lime. Hydrated lime or material that can release it during its hydration (e.g. Portland cement) is then required to activate the natural pozzolans as a binding material. The activity of a natural pozzolan, which is essentially determined by the reactive silica content, is also closely controlled by its specific surface area, chemical and mineralogical composition. Reactive silica is readily dissolved in the matrix as $Ca(OH)_2$ becomes available during the hydration process. These pozzolanic reactions lead to the formation of additional C-S-H with binding properties. Simply, this reaction can be schematically represented as follows:

$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2\ H_2O \rightarrow CaH_2SiO_4 \cdot 2\ H_2O$

or summarized in abbreviated notation of cement chemists

$CH + SH \rightarrow C\text{-}S\text{-}H$

The product of general formula ($CaH_2SiO_4 \cdot 2\ H_2O$) formed is a calcium silicate hydrate, also abbreviated as C-S-H in cement chemist notation, the hyphenation denotes the variable stoichiometry.

TABLE IV
CHEMICAL PROPERTIES OF POFA AND OPC [47].

Chemical composition (%)	OPC	POFA
SiO_2	21.9	59.6-66.9
Al_2O_3	4.9	2.5-6.4
Fe_2O_3	3.3	1.9-5.7
CaO	62.3	4.9-6.4
MgO	2.3	3.0-4.5
SO_3	2.1	0.3-1.3
Na_2O	1.2	0.2-0.8
K_2O	0.3	5.0-7.5
LOI	1.1	6.6-10.0

In bulk, POFA is greyish in colour and becomes darker as the proportions of unburned carbon increase. The properties of POFA and OPCare described inTABLE IV.The main oxide of POFA is silicon dioxideor SiO2. It has been explained that POFA is moderately rich in silicacontent (59.6–66.9%) compared to that of OPC.

In addition, theamount of iron content (1.9–5.7%) is similar to that of CaO, whichis very low, i.e. about 5%. However, it is much finer than OPC and itsspecific gravity is around 1.9–2.4 as mentioned in Table 2. Furthermore,the combustion process influences the amount of carbonpresent in the ash. For instance, Loss on Ignition (LOI) detected8.25%, which is somewhat higher than the maximum value of6.0% stipulated in ASTM C618 [48]. The difference in

TABLE V
THE SELECTED MIX PROPORTION OF HIGH STRENGTH CONCRETE[4, 6,10].

No	Mix proportion (kg/m^3)							W/C	Slump (mm)	Compressive strength (MPa)		Reference
	Cement	POFA		Sand	Coarse aggregate	Water	SP			28-day	90-day	
		kg/m^3	%									
1	495.50	55	10	753	959	176	6.8	0.32	250	60	68	[1]
2	440.0	110	20	745	950	176	8.6	0.32	240	61	70	
3	385.0	165	30	738	940	176	11.6	0.32	250	59	66	
4	400.0	100	20	711	1067	145	11.5	0.28	-	37	52	[2]
5	400.0	100	20	711	1067	145	11.5	0.28	-	49	53	
6	540.4	145.3	25	1057	1340	168	50.4	0.23	169	175	182	[4]
7	214.0	213.0	50	787	961	205	-	0.29	115	41	-	[6]
8	171.0	256.0	60	787	961	205	-	0.29	90	36	-	
9	128.0	299.0	70	787	961	205	-	0.29	80	28	-	
10	504.0	56.0	10	757	971	153	8.5	0.28	200	89	91	[7]
11	448.0	112.0	20	749	962	151	11.8	0.28	185	94	93	
12	392.0	168.0	30	742	952	148	16.9	0.28	185	87	91	
13	270.0	30.0	10	804	1024	216	-	0.72	80	39	40	[10]
14	240.0	60.0	20	801	1021	210	-	0.70	60	32	39	
15	210.0	90.0	30	799	1018	219	-	0.73	75	28	34	

TABLE VI
PHYSICAL PROPERTIES OF POFA[49].

Properties	POFA
Specific surface area	$172 m^2/kg$
% Passing 45- µm sieve	88
Specific gravity	2.1
Color	dark

the amountof the chemical components in POFA is due to the material source,and burning process and efficiency (time and temperature).

No	Mix proportion (kg/m^3)							W/C	Slump (mm)	Compressive strength (MPa)		Reference
	Cement	POFA		Sand	Coarse aggregate	Water	SP			28-day	90-day	
		kg/m^3	%									
1	495.50	55	10	753	959	176	6.8	0.32	250	60	68	[1]
2	440.0	110	20	745	950	176	8.6	0.32	240	61	70	
3	385.0	165	30	738	940	176	11.6	0.32	250	59	66	
4	400.0	100	20	711	1067	145	11.5	0.28	-	37	52	[2]
5	400.0	100	20	711	1067	145	11.5	0.28	-	49	53	
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7	214.0	213.0	50	787	961	205	-	0.29	115	41	-	[6]
8	171.0	256.0	60	787	961	205	-	0.29	90	36	-	
9	128.0	299.0	70	787	961	205	-	0.29	80	28	-	
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15	210.0	90.0	30	799	1018	219	-	0.73	75	28	34	

TABLE *VI*shows the physical properties of POFA. Chindaprasirtet al. [50] reported that the increasing portion of the pozzolanicreplacement and fineness will cause a reduction in the$Ca(OH)_2$ content, while improving the sulphate resistance in concrete.They found that high fineness POFA has a faster pozzolanicreaction than coarse POFA (without sieving). Hence, POFA canimprove the compressive strength of concrete due to its high finenesswhich is denser and more homogeneous. In addition, the useof POFA as a binder satisfies the chemical requirement in ASTMC618 as a pozzolanic material by having a loss on ignition (LOI)of less than 10%. Hence, it could be beneficial in the manufactureof concrete. Many researchers [1, 14, 51,52] have found solutionsfor making use of this by-product to be a valuable waste. In2011, Jaturapitakkul et al. [53] investigated the compressivestrength of mortar due to the pozzolanic reaction of POFA for10–40% of cement replacement by weight of binder. The compressivestrength of mortar due to the pozzolanic reaction of POFA variedfrom 0.1 MPa to 4.5 MPa at 7 days and 2.5 MPa to 22.5 MPa at90 days. This result confirms that the pozzolanic reaction of POFAis small at an early age and increases in significance at a laterage. It also shows that the pozzolanic reaction of POFA increaseswith arising particle fineness, cement replacement rate and ageof concrete. Furthermore, POFA (median particle size of approximately10 lm) has been utilized in the production of HPC, in whichthe highest compressive strength was found to be in the range 60–86 MPa, which was obtained at the POFA replacement level 20% at28 days with a total binder 550–560 kg/m3 [7, 54]. Accordingto Jaturapitakkul et al. [51], the increased fineness of POFA willreduce the expansion and loss in the compressive strength of concrete.

TABLE *V*.For concrete mixtures containing variousproportions of POFA, the result shows that the compressivestrength is more than 55 MPa at 28 days. Concrete samples with20% and 30% POFA show values of 59 and 61 MPa, respectively.After 28-days, the compressive strengths of all concretes containingPOFA were higher than the normal concrete, as mentioned in TABLE *V*. The use of 20% POFA resulted in a compressive strengthof as high as 70 MPa at 90-days. Two different POFA (CAPOFAand ALPOFA) were collected from diverse palm oil industries. Thedifferent mixtures shown in sample G(I) indicate that using additionalfibre (steel) as a binder aggregate to produce a significantcompressive strength of 175 MPa at 28-days compared with nofiber. Meanwhile, at the same POFA proportions of 10%, 20%, and30%, but combined with 10% SF, it produced an extraordinarystrength of up to 93 MPa. Furthermore, POFA can be used as acement replacement up to 30% in producing high-strength concrete,and the compressive strength obtained is higher than concretemade from Portland cement. The inclusion of the ultrafinePOFA tends to reduce the water demand of the high-strength concrete [4]. Overall, the results described and presented show thatPOFA possesses great potential pozzolanic cementing materialswith possibly superior engineering properties in proper mixingand curing systems. It could also lead to the greater utilization ofwaste material from the agricultural side. Subsequently, by minimizingthe volume of waste, which is disposed of landfill, will protectthe environment as well as reduce the emission of GAGs(greenhouse gases CO2). Furthermore, the use of POFA contributesto a sustainable industry and may contribute to a reduction in theconstruction-cost.

CONCLUSION

With the increase in the world's population, sustainable development should be of particular importance and the concrete industryshould contribute to this purpose. One approach can be throughthe use of by-products of Palm Oil industries wastes in concrete. Studiesshow the possibility of use and acceptable performance of certain Palm Oil wastes, e.g. Oil Palm Shell (OPS), Palm Oil Clinker (POC), and Palm Oil Fuel Ash (POFA) as construction materials like coarse and fine aggregates in making concrete. Sinceaggregate makes up about 60–80% of the volume of the concrete,the

substitution of solid waste as full or partial replacement forconventional aggregate contributes significantly in cost effectiveness,energy saving and mitigation of the environmental impactof the construction industry.

Considering the current criteria fora sustainable infrastructure, green building rating systems and relatedenvironmental benefits, making concrete using agriculturalwastes as aggregate can help in making the concrete industry environmentally-friendly.

Therefore, the development of existingknowledge and identification of other useful solid wastes to beused in making concrete will also provide a valuable contributionin the environmental sustainability of the industry.

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