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MECHANICAL PROPERTIES OF LIGHTWEIGHT CONCRETE USING PALM OIL CLINKER: AN OVERVIEW

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Abstract: The use of industrial waste as construction material to build environmentally sustainable structure has several practical and economic advantages. Palm oil clinker is a waste material obtained by burning off solid wastes during the process of palm oil extraction. The research performed over the last two decades concerning the use of palm oil clinker as lightweight aggregates concrete is summarized in this paper. A series of concrete mixes were studied and analysed in replacing the coarse and fine aggregates by palm oil clinker. The mechanical properties of the palm oil clinker lightweight concrete are addressed and discussed. The specific gravity for the palm oil clinker must be less than the normal weight aggregate which is below 2.20. The parameters of mechanical properties were reviewed included compressive strength, tensile strength (flexural and splitting) and Young's modulus. The review showed the positive impact in concrete properties when replaced the normal coarse and fine aggregates with the palm oil clinker. The range of compressive strength of the palm oil clinker lightweight concrete was 30 to 44 MPa. This indicates that palm oil clinker concrete has potential for a replacement which helps in producing a sustainable environment thus contributing to effective construction cost.

Keywords: *lightweight concrete, palm oil clinker, lightweight aggregate, mechanical properties.*

1.0 Introduction

Concrete is the most commonly material used in civil engineering structure as the behavior of concrete itself has an excellent resistance to water and it can be formed to any shape and size required (Shafigh *et al*., 2010). However, the concrete industry consumed most of the natural resources such as water, sand, gravel and crushed rock (Mefteh *et al*., 2013). There are 8 to 12 million tonnes of natural aggregates consumed annually by concrete industries since 2010 (Tu *et al*., 2006).

Construction industry itself involved activities that are not environmentally friendly (Tam, 2009), thus contributes significant impact on social, economic and environment (Pelisser *et al*., 2012). The best way to overcome environmental issues regarding construction activities is using the waste or by-product material to replace the usual raw material in the concrete mixture (Mannan and Neglo, 2010). Palm oil clinker is one of the waste materials that is suitable to replace the aggregates. As Malaysia is one of the world largest producer of palm oil, a large amount of waste from the milling process are produced. (Ahmad *et al*., 2007). Malaysia contributes in a total of 58% palm oil to the world supply and has been the top listed countries with huge resources of oil palm shell (OPS) (Ahmad *et al*., 2010).

Many benefits can be gained by applying lightweight concrete (LWC) in a structure as it can reduce the dead load (Bremmer and Eng, 2001). In order for a lightweight concrete to be produced, lightweight aggregate (LWA) are generally used in the LWC mix. In many cases, LWA used in the lightweight concrete is a coarse aggregate (Shafigh *et al*., 2012). An extensive research has been carried out by the previous researchers to produce the LWA by utilising palm oil clinker (POC) as aggregate in replacing the conventional material for both coarse and fine aggregates. The physical and mechanical properties of the palm oil clinker concrete (POCC) has been established (Mohammed *et al*., 2013). POCC compressive strength can easily achieve more than 17 MPa, which is a minimum requirement for structural lightweight concrete according to ASTM C330 (Mohammed *et al*., 2011).

Researchers concluded that the chloride permeability of POCC is acceptable for conventional concrete and confirmed the viability of POC to be used as aggregate in producing the durable structural LWC (Mohammed *et al*., 2011). POC is well graded and it is suitable for use in concrete work. The porous physical structure of coarse POC can be filled by fine aggregate and the pore of its fine aggregate filled with cement paste to formed a strong mix of concrete (Mindess *et al*., 2003) .

The main objective of this study is to make overview the potential used of the POC as LWA in concrete. The detailed study was conducted to identify the mechanical properties of the concrete by using POC in different concrete mix and to be reviewed in this paper.

2.0 Concrete Mixture

2.1 Mix Proportion

The compressive strength of the concrete mix depends on the hardened density of the concrete. The density of lightweight concrete is below than 2000 kg/m³ compared to the density of normal weight concrete which is 2400 kg/m³. According to Clarke (2002) density of lightweight concrete range between 1200 to 2000 kg/m³. Table 1 shows several mix proportions from selected researchers using POC as their replacement material of aggregate to improve the strength and to produce a lightweight structure. Mohammed *et al*., (2014) in their study, replaced 100% fine and coarse aggregates with POC. The mixtures were labelled A1, A2, A3, A4 and A5. The density of the concrete is in the range of 1818.20 to 1845.60 kg/m³. Cement contents used in all mixtures are between 480 to 520 kg/m³ and the water/cement ratios used are between 0.40 to 0.46 for all samples. Noor Mohamed (2001) replaced 100% conventional fine and coarse materials with POC and the concrete density obtained in fresh concrete condition is 1950 kg/m³. Notation listed in summary given as follows:

POC : Palm Oil Clinker
OPC : Ordinary Portland Cement
C : Coarse Aggregates
F : Fine Aggregates
NWC : Normal Weight Concrete
F.A : Fly Ash

Table 1 : Mix proportion

Mix details	*Cement content (kg / m³)*	*w/c ratio*	*Mix proportion*	*Concrete density (kg / m³)*	*References*
A1	480 – 520	0.40 – 0.46	OPC + POC (C + F)	1845.60	(Mohammed *et al*., 2014)
A2			OPC + POC (C + F)	1835.70	
A3			OPC + POC (C + F)	1832.90	
A4			OPC + POC (C + F)	1820.50	
A5			OPC + POC (C + F)	1818.20	

Table 1 (con't) : Mix proportion

Mix details	*Cement content (kg / m³)*	*w/c ratio*	*Mix proportion*	*Concrete density (kg / m³)*	*References*
NWC	401	0.47	OPC + SAND (F) + Granite (C)	2370	(Roslli Noor Mohamed, 2001)
LWC	512.50	0.44	OPC + POC (C + F)	1950	
S1	382	0.55	NWC (control mix)	2486	(Ahmad *et al.*, 2007)
S2	420	0.55	OPC + POC (C) + Sand	2018	
S3	420	0.55	OPC + POC (C + F)	1846	
S4	378	0.55	OPC & F.A + POC (C+F)	2026	
S5	378	0.55	OPC & F.A + POC (C) + Sand	1878	
M-1	-	0.20	OPC + POC (C + F)	1837.80	(Mohammed *et al.*, 2013)
M-2		0.40	OPC + POC (C + F)	1830.30	
M-3		0.60	OPC + POC (C + F)	1820.10	
M	500	0.38	OPBC 0% + Sand 100% + OPS	1996	(Shafigh *et al.*, 2014)
M12.5	500	0.38	OPBC 12.5% + sand 87.5% + OPS	1989	
M25	500	0.38	OPBC 25% + sand 75% + OPS	1993	
M37.5	500	0.38	OPBC 37.5% + sand 62.5% + OPS	1948	
M50	500	0.38	OPBC 50% + sand 50% + OPS	1919	

According to Ahmad *et al*., (2007), there were various proportions made. However, usage of POC as coarse aggregates in every sample is constantly 100%. For sample S2, 100% of sand used as fine aggregate besides ordinary Portland cement (OPC) as a binder. Sample S3 used 100% POC fine aggregates and 100% OPC which is 420 kg/m³ in weight proportion. For sample S4 the binder used are 90% OPC and another 10% was fly ash. S5 proportion used 100% POC for both coarse and fine aggregates. The binder was 90% OPC together with 10% fly ash. The density of concrete for sample S3 and S5 meet the lightweight concrete requirement which is below 2000 kg/m³ (Teo *et al*., 2006). Shafigh *et al*. (2014) prepared five samples with different percentage usage of POC as fine aggregate and fixed using oil palm shell as coarse in every mixture. The samples are labelled with M, M12.5, M25, M37.5 and M50 which presented the percentage of POC fine aggregates used. Cement content and water/cement ratio were fixed with 500 kg/m³ and 0.38 respectively.

3.0 Mechanical Properties

3.1 Compressive Strength

Compressive strength is the most important strength indicator in mechanical properties of the concrete structure. It can affect the other elements of mechanical properties such as flexural strength, splitting tensile strength and modulus of elasticity (MOE). According to ACI guideline, LWC compressive strength for 28 days should not be less than 17 MPa (Neville and Brooks, 2008). Some of the researchers using 100% of POC to replace the conventional aggregates for both fine and coarse. Some other researchers only replaced the common material of concrete with POC by certain percentages. Mohammed *et al*., (2013; 2014) had prepared five mix proportions using OPC as a binder and 100% replacement of typical materials for both fine and coarse aggregates with POC. The concrete mixes with various water cement ratios and the lowest cement ratio is 0.20. The first five batches of samples is labelled A1, A2, A3, A4 and A5 and the compressive strength were 42.56, 32.08, 27.15, 26.52, 25.50 and 33MPa respectively. The range of water cement ratio has been used in this batch is 0.40 to 0.46. For the second batch mix proportions, the researchers prepared three samples with water cement ratios of 0.20, 0.40 and 0.60. Compressive strength from this batch is 46.80, 31,50 and 20.30MPa subsequently. From the eight mix proportions, the highest compressive strength is 46.80 MPa while cement ratio used is the lowest with 0.20.

In Noor Mohamed (2001) research, two mix proportions of normal weight concrete (NWC) and lightweight concrete (LWC) using 100% POC as fine and coarse aggregates were prepared. POC concrete was compared to NWC to justify its potential to be used in structural members. Compressive strength results obtained that POC concrete compressive strength (44.40 MPa) was slightly less than NWC (46.10 MPa) by 3.7%. Ahmad *et al*., (2007) differentiated their mix proportions by designing the control mix using Department of Environmental (DOE) and LWC using FIP design method. S1 is a control mix (NWC) and the other four mix proportions (S2, S3, S4, S5) are LWC. All of the LWC mix proportions used 100% POC for coarse aggregate. Compressive strength for S1 is 50MPa while compressive strength for S2 is 41.60MPa which is 16.80% reduction of the compressive strength from NWC. As S4 is designed similarly to S2 with difference in fly ash addition of 10% hence, there was not much different in its compressive strength. The significant reduction of compressive strength in S3 and S5 are approximately 32% lower compared to NWC.

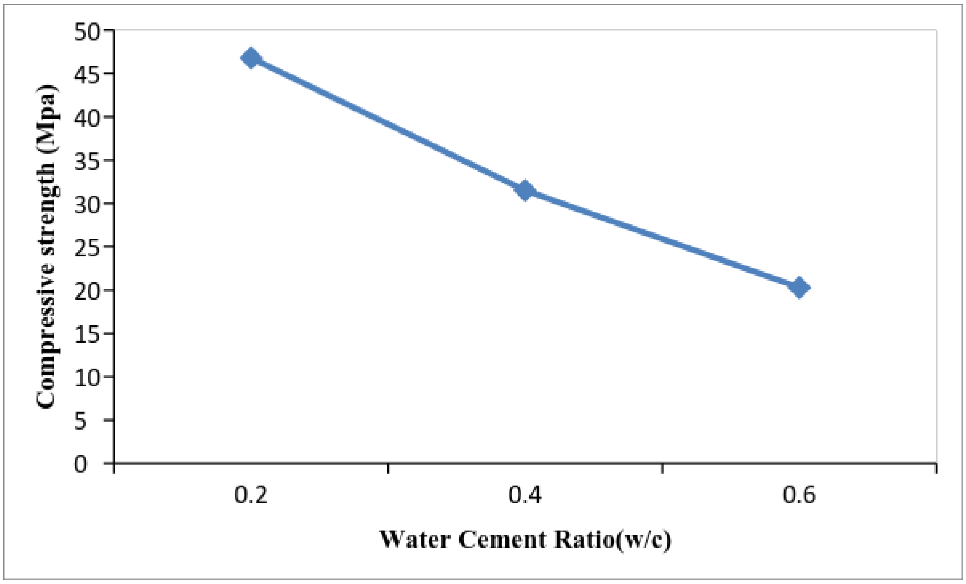

Figure 1: Compressive strength with different cement ratio (Mohammed *et al*., 2013)

Shafigh *et al*. (2014) studies were by using 100% oil palm shell OPS as the coarse aggregate and the natural fine material is replaced with oil palm boiler clinker (OPBC) for a certain percentage. For the M mix proportion, 100% natural sand are used and compressive strength obtained from the mix is 37MPa. The compressive strength of M recorded is identical as M25. M25 mix proportion used 100% OPS as coarse aggregates and replaced 25% of natural sand with OPBC as fine aggregates. For M12.5 sample used 12.50% OPBC replacing the sand in fine aggregates but there is 2.70% reduction of compressive strength for M12. The decreasing values of compressive strength approximately 12.50% are detected for M37.5 and M50 as the replacement of OPBC increased.

3.2 Flexural Strength

Determination of the modulus of rupture (MOR) or flexural strength for palm oil clinker concrete (POCC) has been carried out by various researchers as stated ni Table 2. There are several researchers that conducted researches on replacing the natural material for both fine and coarse aggregates with 100% POC to produce POCC. Mohammed *et al*., (2014) conducted an experiment on POCC. Due to the porous characteristic of the POC, the flexural strength obtained are in the range of 3.46 to 4.64 MPa. It is approximately 10% of its compressive strength. Noor Mohamed, (2001) reported that the POC concrete mixture flexural strength was roughly 6 MPa which 13% of its compressive strength. Ahmad *et al*., (2007) prepared four LWC mixtures. There are two design mix proportions S2 and S4 using 100% natural sand for fine and 100% POC as coarse aggregate, but for S4 mix they replace 10% OPC as binders with fly ash and the flexural strength obtained was 6.40 – 6.43MPa which means it is 15% of its compressive strength. The flexural strength for both mix S3 and S5 respectively are 5.43 MPa and 5.46 MPa. The replacement of OPC with 10% fly ash did not make any significant increment to the flexural strength due to the high water absorption behaviour of fly ash. Shafigh *et al*., (2014) conducted an investigation on mix proportion using 100% oil palm shell as coarse aggregate and replaced natural sand as a fine aggregate with a certain percentage of POC. Replacement made for mix M12.5 with 12.50%, 25% for mix M25, 37.50% for mix M37.5 and finally 50% of replacement for M50. The flexural strength is in the range of 3.22 to 4.18 MPa.

3.3 Splitting Tensile Strength

For some of the structural design members such as slabs and highway, resistance to cracking and shear strength are the crucial properties to be investigated (Neville, 2008). Mohammed *et al*., 2013; Mohammed *et al*., 2014) in their experimental research, obtained the splitting tensile strength in range 1.80 to 2.72 MPa with water cement ratio from 0.2 to 0.6.

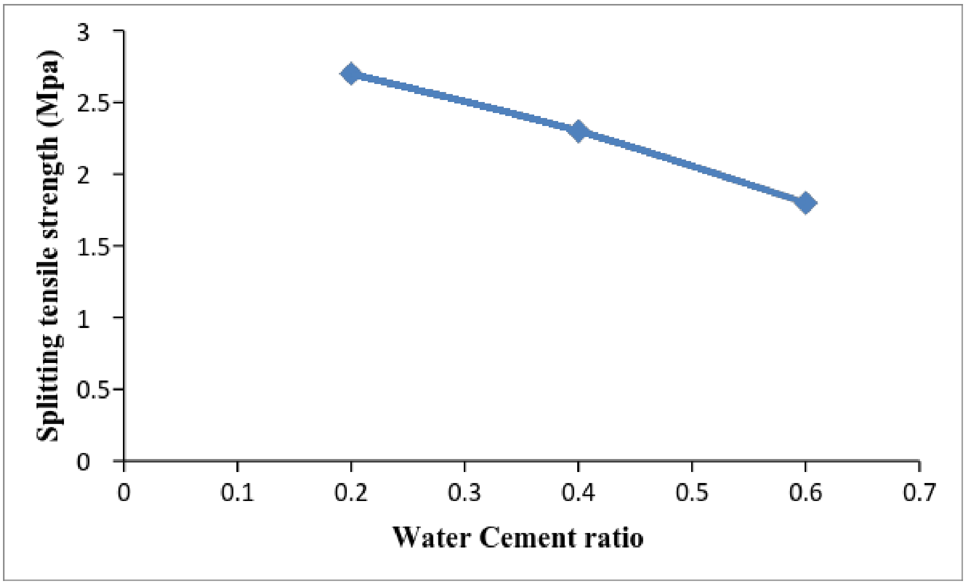

Figure 2: Splitting tensile strength at some value of w/c ratios. (Mohammed *et al*., 2013)

Figure 2 shows that the splitting tensile strength decreases when the w/c ratio value was increased. Table 1 and 2 stated that lower LWA content will increase the splitting tensile strength. Noor Mohamed, (2001) result for splitting tensile strength was 3.17 MPa with LWA content 1133 kg/m³. Ahmad *et al*., (2007) in other hand obtained 2.30 MPa for tensile strength with LWA content 1350 kg/m³.

3.4 Modulus of Elasticity (MOE)

The modulus of elasticity or Young's modulus is a test to measure the stiffness of the concrete in structural members. Mohammed *et al*., (2014) reported that by increasing the w/c ratio the E-value will be reduced. In different mix proportions with w/c ratio 0.20, 0.40 and 0.60, the MOE result was about 2.70 MPa, 2.30 MPa and 1.80 MPa respectively. Shafigh *et al*., (2014) prepared various mix proportion of LWC using 100% OPS as coarse aggregate, natural sand, and POC as fine aggregate. The range of MOE values between 8.60 GPa and 13.80 GPa. Noor Mohamed, (2001) reported from his studies the value of MOE for NWC was 30 GPa. The agreement was supported by Neville, (2008) which the result of MOE reduced when normal weight aggregates was replaced with lightweight aggregate.

3.5 Summary of Previous Research Studies

Table 2 shows the summary of mechanical properties of concrete from previous researchers. The POC concrete showed the flexural strength in the range of 10 to 20% of the compressive strength whereas the range of 6 to 10% for splitting tensile strength. The MOE value of these LWC was found in a range of 8.6 GPa to 27GPa.

Table 2: Summary of mechanical properties of concrete from previous researchers

Mix Details	*Compressive strength (MPa)(28d)*	*Flexural strength (MPa)*	*Splitting tensile strength (MPa)*	*Modulus of elasticity (GPa)*	*References*
A1	42.56	4.64	2.72	26.94	(Mohammed *et al.*, 2014)
A2	32.08	4.38	2.51	19.35	
A3	27.15	4.01	2.26	16.87	
A4	26.52	3.64	1.90	12.61	
A5	25.50	3.46	1.85	9.73	
NWC	46.10	6.43	3.31	30	(Roslli Noor Mohamed, 2001)
LWC	44.40	6.09	3.17	22	
S1	50.00	8.02	4.20	-	(Ahmad *et al*,. 2007)
S2	41.60	6.40	3.25		
S3	34.00	5.43	2.30		
S4	42.00	6.43	3.30		
S5	36.50	5.46	2.30		
M-1	46.80	-	2.70	26.80	(Mohammed *et al.*, 2013)
M-2	31.50		2.30	16.90	
M-3	20.30		1.80	9.70	
M	37.00	4.18	2.64	13.80	(Shafigh *et al*,. 2014)
M12.5	36.00	4.15	2.57	13.00	
M25	37.00	3.84	2.49	12.60	
M37.5	33.00	3.73	2.41	12.40	
M50	32.00	3.22	2.20	8.60	

4.0 Conclusions

The application of POC as LWA in POC concrete was reviewed through previous studies that had been conducted. The experimental research to determine the mechanical properties of LWC using POC in the various concrete mix proportion has been conducted by many researchers and are the conclusion that can be drawn are as follow:

1. The range of compressive strength of LWC were 20 to 47 MPa when the mix proportion was using POC as both fine and coarse aggregate with OPC as binders in the concrete mixture.

2. The hardened density of the POC concrete was approximately between 1818 – 1845 kg/m³, which mean the POC concrete meet the requirement of LWC that the usual density is less than 2000 kg / m³.

3. The POC aggregate is a porous material and tend to absorb a high amount of water compared to normal weight aggregates.

4. The replacement of POC as coarse aggregates and fine aggregates has insignificant impact on MOE, flexural and splitting tensile strength.

5. The POC aggregates have high potentiality to be us as aggregates replacement for the lightweight concrete.

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