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Properties of Oil Palm Shell Lightweight Concrete with Ceramic Tile Powder as a Partial Cement Replacement

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ABSTRACT

Globally, the concrete production continues to expand with rapid urbanization. Environmental pollution caused by release of greenhouse gases of cement factory, disposal of ceramic tile waste from construction project and dumping of oil palm shell of palm oil mills need to be resolved. Therefore, a new ecologically friendly concrete materials formed using industrial wastes as mixing ingredient should be used. The current study investigates the influence of ceramic tile powder as a partial substitution for cement on the workability and hardened properties of oil palm shell concrete. A total of six mixtures were tested, each containing different percentage of ceramic tile powder in relation to the weight of the cement: 0%, 10%, 20%, 30%, 40% and 50%. All samples were water cured up to 28 days before testing. The mixtures were tested to determine the workability, dry density, compressive strength, splitting tensile strength and water absorption. Blending of 10% ceramic tile powder improves the compressive strength of oil palm shell concrete owing to pozzolanic reaction effect. Integration of ceramic tile powder up to 50% produce concrete with water absorption lower than 10% indicating its good quality. Success in blending ceramic tile powder in oil palm shell concrete production would reduce waste accumulation at wasteyard and lower cement consumption for greener environment.

1. Introduction

Worldwide, concrete consumption is over 25 billion tonnes per year [1]. Global production of concrete continues to grow along with the expansion of the construction industry. Rising concrete production also increases production of the raw materials namely cement, sand, coarse aggregate and water. Excessive quarrying of gravel tends to destroy the green landscape which is the habitat of diverse flora and fauna which finally would affect the ecosystem. According to Lyngseth and Krok [2], every phase of a quarry's life cycle comes at a massive ecological cost including disruption of natural

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streams and springs. In 2024 the production of mining and quarrying will reach 41,900 million kg [3]. This number is expected to rise along with the expanding of concrete industry demand. Other than that, cement trade also flourishes along with the prosperity of concrete business. Global cement production reaches up to 4.1 billion tons [4]. This industry continues to consume larger quantity of raw material classified as natural resources process and releases undesirable pollutants during its manufacturing process [5]. Annually, approximately 2.7 billion tons of CO_2 are released to the environment [6]. Industrial air pollutants, including sulphur dioxide, nitrogen oxides, and carbon monoxide, are thirdly caused by the cement sector [7]. In view of cleaner and sustainable environment, researchers are continuously investigating the potential use of wastes generated from diverse industry to be employed as supplementary cementitious material (SCM) in cement-based composites since last few decades.

In relation to that, environmental polluting waste generated from the expanding palm oil industry and construction industry has also considered to be used for sustainable concrete production. The palm oil sector in Malaysia is producing around 19.14 million metric tons of palm oil and projected to reach up to 26.6 million metric tons by 2035 [8,9]. Having around 457 oil palm mills and possessing a treating capacity of 116.81 million tons of fresh fruit bunches (FFB) annually [10], this industry also generates huge amount of industrial waste. The biomass waste produced by palm oil plantations and mills in 2020 exceeded 311 million tons [11]. Oil palm shell is a kind of biomass waste which obtained after harvesting of oil from the fruit. According to Ting *et al.,* [12], palm oil shells are generated more than 4.56 million tonnes annually. Disposal of OPS tend to pollute the surrounding environment for years [13]. Option of burning oil palm shell causing greenhouse effect and resulting in depletion of the ozone layer less preferred. Realization on the negative impact of natural aggregate quarrying, OPS has been used as coarse aggregate to create lightweight aggregate concrete since 20th century. The utilize of oil palm shell (OPS) in concrete has promise for enhancing environmental sustainability via the mitigation of reliance on non-renewable gravel and the promotion of waste reuse which makes this product continue to be explored its potential. The distressing cement industry issues has led to development of greener oil palm shell lightweight concrete containing waste as cement substitution such as fly ash [14], slag [15] and POFA [16,17]. More waste with cementitious properties remains to be explored its potential in oil palm shell concrete.

The availability of ceramic tile waste generated to construction activity in building trade opens the door for the exploration of its use in oil palm shell concrete. Construction and demolition waste (CDW) is increasing in tandem with the worldwide phenomenon of urbanisation. The building and demolition trash surpasses 10 billion tonnes per year [18]. Consequently, the contribution of CDW to the overall solid waste producing has increased to around 30-40% [19-21]. Ceramic waste (CW), a byproduct from CDW, contributes to environmental damage when disposed of in dumpsites. It is predicted that 45% of CDW are ceramic [22,23]. The disposal of ceramic waste from CDW in landfill sites leads to environmental damage [24]. The inherent non-biodegradability of waste from construction industry has resulted in enduring challenges such as illicit disposal, ecological contamination, and health concerns.

Subsequently, option of recycling ceramic waste for product development would reduce quantity discarded at dumpsite and lessen environmental pollution issue. It is worth noting that the impact of CTP as a cement substitute on OPS concrete has not yet been investigated. Consequently, in recent years, scientists have shifted their focus towards using CW as a partial substitution to cement in the construction sector. The blending of CW as a substitution for cement in concrete has the potential to significantly reduce the environmental consequences linked to the concrete industry and the disposal of CDW. Ceramic tile waste has been explored its performance when blended as partial cement substitution in mortar [25-27], normal concrete [28] and self-compacting concrete [29]. However, the very limited research reports the impact of utilizing CTP as partial cement substitution in OPS concrete. Thus, the current research explores the mechanical performance of OPSC containing CTP as partial cement substitution.

2. Methodology
2.1 Materials

Ordinary Portland cement (OPC) in adherence with ASTM C 150 [30], was utilized for the study. The used OPC had a specific surface area of 913 m^2/kg and a specific gravity of 3.10. The ceramic tile wastes were collected from tile supplier. The ceramic tile was then dried in an oven at 110 °C for 24 hours. Then, the ceramic tile waste was processed to be fine powder to meet the ASTM 618 [31] particle size requirements (66% pass 45 µm) enabling it to be used as pozzolanic ash. Figure 1 illustrates the ceramic tile waste in pieces and after ground to be powder ready to be blended as partial cement substitution material. Table 1 tabulates the chemical properties of binders used. Crushed oil palm shells were sourced from a nearby palm oil refinery and used as coarse material. The OPS was processed to eliminate the fibres before it is used. Figure 2 illustrates images of the original condition of OPS from the mill and after it is processed. River sand was utilized in this study. Clean water was employed for concrete specimen preparation and curing. Superplasticizer is integrated to maintain low water cement ratio while maintaining workability of mixture.

(a) (b)

Fig. 1. (a) Discarded ceramic tile (b) Ground ceramic tile powder

Table 1
Oxide composition of binders

Binder type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
OPC	12.35	2.39	4.05	74.7	0.49	4.1	-	0.89
CTP	57.1	16.6	4.19	5.34	1.10	0.22	1.24	2.60

(a) (b)

Fig. 2. (a) OPS before processed (b) OPS after processed

2.2 Mix Proportion

Six samples were prepared. A control sample (OPS-0%CTP) produced using OPC as sole binder were utilized as control sample. Another five samples (OPS-10%CTP to OPS-50%CTP) containing 10%, 20%, 30%, 40%, and 50% CTP as partial cement substitution were produced. A constant water cement ratio used for all mixes. Table 2 tabulated the mix proportion used. A clean concrete mixer was used to blend all the accurately measured mixing ingredients. Firstly, OPS, sand, CTP, and OPC were subjected to dry mixing process. The water and superplasticizer were then added to the concrete and mixed completely. The concrete mixture in the mould was subjected to compaction process using a vibrating table. On the following day, the hardened concrete was taken out from the mould and appropriately branded prior to being submerged in water for curing.

Table 2
Mixture proportions for OPS-concrete (kg/m³)

Mix	Cement	Ground CTP	OPS	Sand	Water	Superplasticizer
OPS-0%CTP	540	0	193	848	216	7.191
OPS-10%CTP	486	54	193	848	216	7.191
OPS-20%CTP	432	108	193	848	216	7.191
OPS-30%CTP	372	162	193	848	216	7.191
OPS-40%CTP	324	216	193	848	216	7.191
OPS-50%CTP	270	270	193	848	216	7.191

2.3 Testing

The workability of the concrete was evaluated utilizing a slump test in adherence with BS EN 12350-2 [32]. The surface of the round table and Mold was moistened and scrubbed. To reach the near edge of the concrete, the tamping rod is placed at an angle and then spiralled back to the canter to reach the bottom layer. Pouring and compacting the concrete on the cone is the final stage. Next, any unevenness in the concrete is evened out with a tamping rod. Compressive strength was measured 7, and 28 days after fabrication adherence to BS EN 12390-3 [33]. The average result for each test condition was determined by testing three samples. Splitting tensile strength was measured 7, and 28 days after fabrication in align with BS EN 12390-6 [34]. Water absorption testing was carried out on 28-day water-cured samples in align with the procedure described in the BS1881-122 (2009) [35]. Figure 3 depicts slump test and compressive strength in progress.

(a) (b) (c)

Fig. 3. Testing in progress (a) Slump test (b) Compressive strength test (c) Splitting tensile strength test

3. Results
3.1 Fresh Properties

Figure 4 illustrates the effects of adding CTP as a partial cement substitution in palm oil shell concrete (OPSC) on slump values. The changes in slump pattern upon increase in CTP quantity add is presented in Figure 5. The outcomes showed a considerable correlation between the increase in CTP content and a significant improvement in the workability of the OPSC. The slump values for samples with proportions of 0%, 10%, 20%, 30%, 40%, and 50% were 130 mm, 150 mm, 170 mm, 190 mm, 210 mm, and 220 mm, respectively. Replacement of half of the cement content with CTP, leading to an increase of 169% relative to the reference samples. It is obvious that the workability of the OPSC is influenced by the utilization of CTP, which has different properties than OPC. A similar behaviour has also been noted in concrete upon integration of various kind of pozzolanic ash by previous researchers, Mo *et al.,* [15], and Shafigh *et al.,* [36].

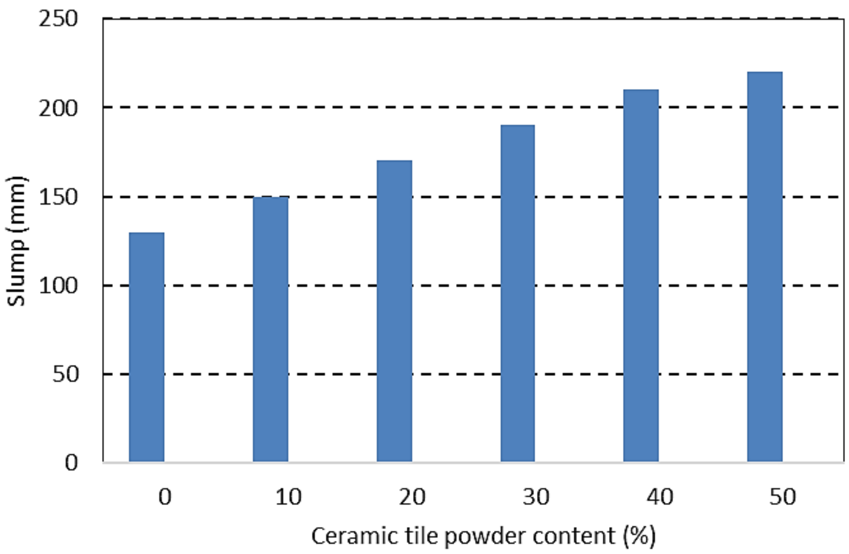

Fig. 4. The influence of CTP concentration as a replacement of OPC on the workability of OPSC

Fig. 5. The effect of CTP content on concrete slump pattern

3.2 Dry Density

As depicted in Figure 6, the dry density of all OPS-concrete mix ranges from 1700 kg/m^3 to 1850 kg/m^3. Increasing the CTP replacement levels in the concrete's binder content has been shown to result in a decline in the density of the OPSC. The most significant drop in OPSC density occurred when 50% of CTP was used as a cement replacement, resulting in an 8% reduction relative to the reference samples. The decrease in density is owing to the inferior specific gravity of CTP relative to OPC. The influence of lower specific gravity of different types of pozzolanic ash known as wood ash on the density of concrete produced using specific agricultural ash has been pointed out by Chowdhury *et al.,* [37]. This may be owing to the comparatively inferior specific gravity of CTP in relation to cement [38]. On overall, all the mixes can be considered as lightweight concrete in adherence to BS EN 206 Part 1 [39] as the dry density value does not exceed 2000 kg/m^3. A similar pattern has also been observed by previous researchers Ting *et al.,* [12] and Mo *et al.,* [40] who utilized different types of pozzolanic ash.

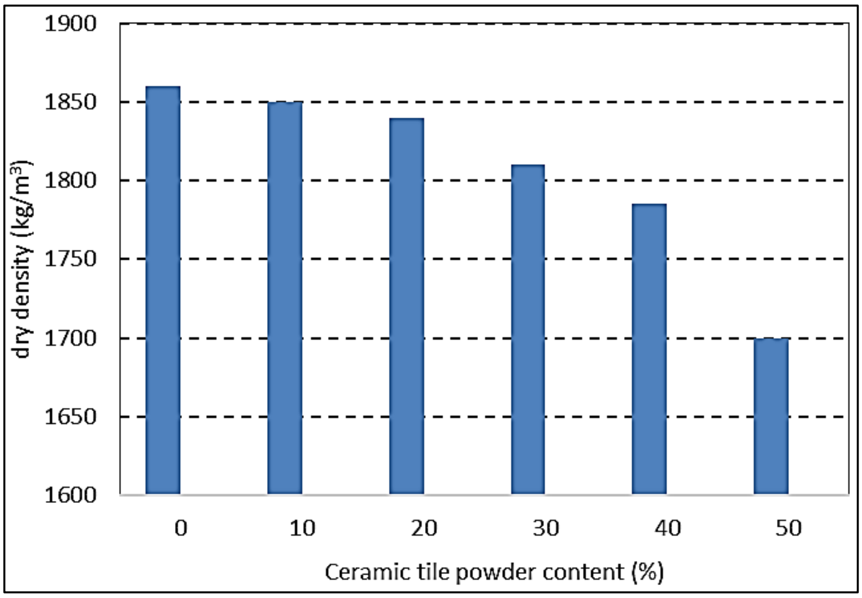

Fig. 6. The influence of CTP concentration as a replacement of OPC on dry density of OPSC

3.3 Compressive Strength

The compressive strength of the OPSC is influenced by the CTP level, as illustrated in the Figure 7. The compressive strength values of all OPSC mix vary between 18 MPa and 10.89 MPa during the 7-day curing age and between 18.7 MPa and 12.07 MPa during the 28-day age. The findings show that an initial improvement in compressive strength occurred when 10% CTP was utilized as a cement substitution relative to the control mix throughout the curing period. The rise in compressive strength at 10 %CTP content can owing to the formation of a more CSH gel benefitting from hydration and pozzolanic reaction. The positive contribution of 10% CTP as pozzolanic ash on mechanical strength of construction material has been observed in self-compacting concrete [28] and mortar [24].

However, the strength decreased with increasing CTP content beyond 20%. The strength declination of cement-based composites when integrated with higher amount of pozzolanic ash is due to lower cement content that produce smaller quantity of CSH gel and lesser calcium hydroxide for development of pozzolanic reaction. As a result, the sum of CSH gel produced from both hydration and pozzolanic reaction is lesser than the mix containing smaller amount of CTP. The strength of OPSC decreases by 35 % when 50 % CTP is used as a substitute for cement. Similar trend has been observed by prior researchers, Muthusamy and Zamri [41] and Mo *et al.,* [42] involved investigating compressive strength of concrete upon integration of high content of pozzolanic ash.

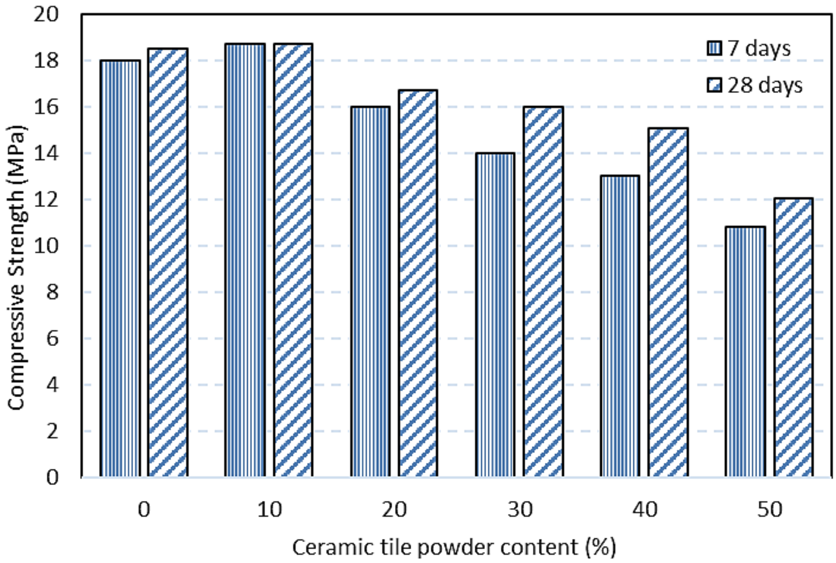

Fig. 7. The influence of CTP concentration as a replacement on the compressive strength of OPSC

3.4 Splitting Tensile Strength

Figure 8 illustrates the results of the splitting tensile strength value at the curing phase of 7 and 28 days. The splitting tensile strength values of all OPSC specimens vary between 1.51 MPa and 0.76 MPa during the 7-day curing period and between 1.76 MPa and 0.97 MPa during the 28-day curing period. Employment of water curing has promoted undisturbed chemical reaction of the cementitious material aiding strength increment of the mixes as curing become longer. Blending of 10% CTP produces concrete with comparable splitting tensile result of 1.76 MPa close to the reference sample 1.72 MPa. Nevertheless, a notable reduce in tensile strength was seen when the substitution quantity was augmented above 20%. The greatest reduction of 44 % was observed for the OPSC that contained 50 % CTP. The observed decrease in strength with a cement replacement of more than 20 % by CTP can be owing to the reduced formation of hydration products, which is associated with the lower content of the cement. Previous researchers Muthusamy *et al.,* [16] have also found a similar pattern of behaviour upon the integration of different types of pozzolanic ash in OPSC.

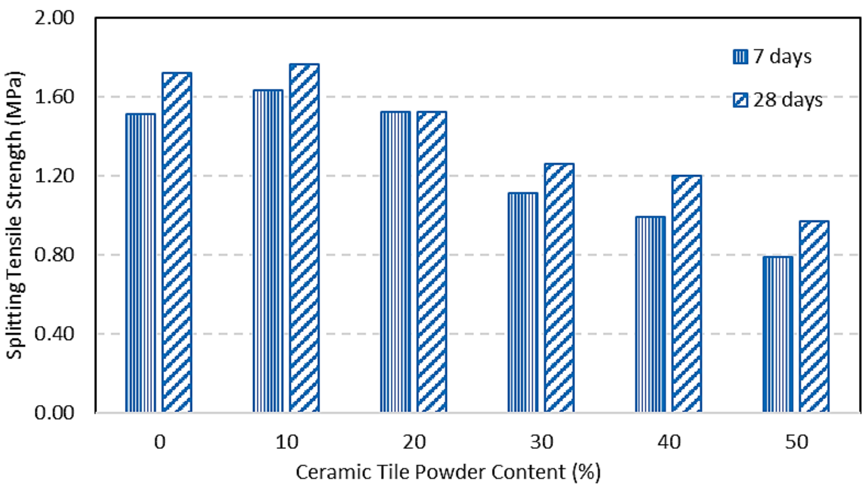

Fig. 8. The influence of CTP concentration as a replacement on the compressive strength of OPSC

3.5 Water Absorption

Figure 9 displays the water absorption of concrete mixes is between 4.5% to 9.1%. The findings indicated that the mixes with 10% of CTP have comparable water absorption (4.8%) relative to the reference sample (4.5%). Both mixes demonstrated a satisfactory result. Previous researcher, Wilmshurst [43] has pointed out that exceptionally high-water absorption rate of 4 to 5% by mass. Apparent rise in water absorption value is seen upon integration of 20% CTP onwards. Increasing the CTP by 50% lead to a considerable rise in water absorption, with a rise of up to 89% compared to the control samples. CTP increases OPSC porosity by reducing the amount of hydration products in a cementitious matrix. Therefore, the observed enhancement in the water absorption capacity of the CTP-OPSC mixes may be owing to the corresponding augmentation in the pore volume of the concrete mixes. Overall, all mixes may be categorised as high-quality concrete as none of the water absorption outcomes above 10%. Neville [44] classifies concrete as high-quality if its water absorption is below 10%.

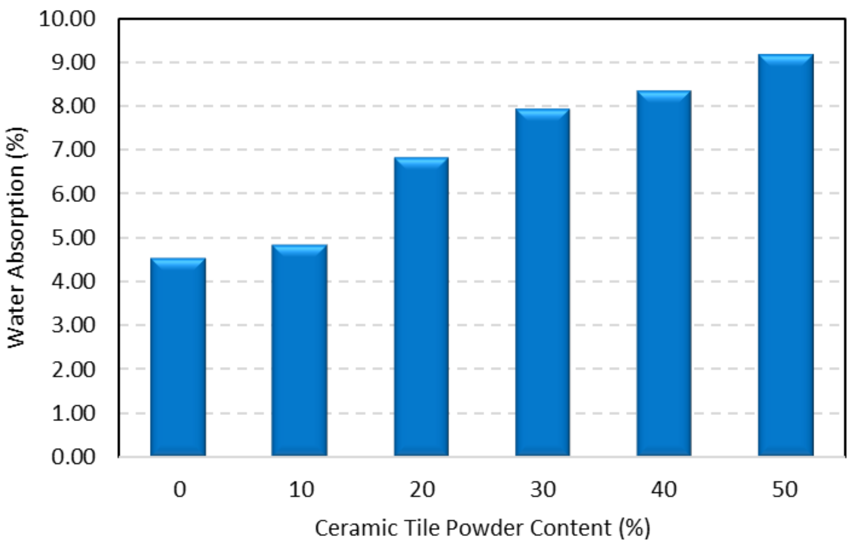

Fig. 9. The influence of CTP concentration as a replacement on the water absorption of OPSC

4. Conclusions

The incorporation of up to 10 % CTP as a OPC substitute in palm oil shell concrete increases its compressive strength. The use of a maximum of 10 % CTP has a similar splitting tensile strength. Nevertheless, the excessive utilize of CTP in the production of palm oil shell concrete leads to a significant reduce in strength. OPSC mixes comprising up to 50% is considered as good quality concrete.

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