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Review of palm oil fuel ash and ceramic waste in the production of concrete

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Abstract. High demand for cement in the concrete production has been increased which become the problems in the industry. Thus, this problem will increase the production cost of construction material and the demand for affordable houses. Moreover, the production of Portland cement leads to the release of a significant amount of CO_2 and other gases leading to the effect on global warming. The need for a sustainable and green construction building material is required in the construction industry. Hence, this paper presents utilization of palm oil fuel ash and ceramic waste as partial cement replacement in the production of concrete. Using both of this waste in the concrete production would benefit in many ways. It is able to save cost and energy other than protecting the environment. In short, 20% usage of palm oil fuel ash and 30% replacement of ceramic waste as cement replacement show the acceptable and satisfactory strength of concrete.

1. Introduction

Palm oil fuel ash (POFA) is an agricultural waste produced from the combustion of oil palm plant residue in palm oil industry [1]. Both husks and shells are burnt in the boiler after the extraction of oil from palm oil fruit to produce steam for the turbine engine which generates electricity for use in the palm oil mills [2]. After the combustion in the boiler, 5% of ash produced which known as POFA is generally disposed of in open fields. This situation created the problems to the environmental and health problems [3-4].

Polishing process of ceramic tiles produced ceramic waste powder are dumped in landfills and can cause soil, air and groundwater pollution making a serious environmental problem [4]. The increases large piles occurs due to ceramic waste that disposed of factories producing construction industry materials and has been accumulating on frequently [5]. Ceramic industry has produced about 15% to 30% of waste material from the total production. However, this waste is not recycled in any form at present. Ceramic waste was characterized as durable, hard and highly resistant to biological, chemical and physical degradation forces [6].

2. POFA in concrete production

Mohammadhosseini et al. [7] present the study on the performance of concrete containing waste carpet fibers and POFA. This study only replaced cement with 20% POFA and 0%to 1.25% of carpet fiber used with OPC. In short, the replacement of cement with POFA resulted in lower workability. Moreover, the use of 0.75% carpet fibers and 20% POFA in concrete shows the decreases of drying shrinkage.

Ahamed and Siddiraju [8] study the strength of concrete with POFA as cement replacement. This study replaced the cement by 5%, 7.5%, 10%, 12.5%, 15% and 17.5% compared with conventional concrete of grade M_{25} and the test is conducted for 3, 7 and 28 days. Researchers found that 12.5% is the optimum replacement of cement in the concrete production whereas it shows the increases in the strength. For the compressive strength test, it shows 34.3 MPa at age of 28 days while split tensile strength gave the result of 3.4 MPa.

For the experiment carried out by [9], the researchers study the effect of POFA in producing economical and eco-friendly self-compacting concrete. The study has replaced the cement by 0%, 50%, 60% and 70% with constant water/cement ratio of 0.35. The results found that fresh properties of SCC containing a high volume of treated POFA are better than control in terms of filling ability and passing ability. In the other hands, segregation index remains in the range specified by the EFNARC guidelines. In summary, the compressive strength of SCC containing 50% to 70% of treated POFA was higher than control at 28 days and beyond. Moreover, lower shrinkage occurred to all SCC specimens compared to control SCC after 12 months of drying shrinkage. The researchers conclude that the replacement of cement with high volume POFA can reduce the cost production of SCC with 8% to 12% compared with the normal SCC.

Research carried by Ranjbar et al. [10] used volume 10%, 15% and 20% of POFA as replacement of cement in the production of self-compacting concrete to study its durability and mechanical properties. Water to cement ratio used in this study was 0.35 for all specimens. In short, the researchers found that POFA is a great potential as the replacement of cement in SCC. However, POFA caused the reduction in workability of SCC but this can be improved by the additional of superplasticizer. The increases of POFA content lead to the reduction in early mechanical properties but the final strength of the SCC containing POFA was comparable with normal SCC. In addition, the SCC containing POFA showed the less surface water absorption and higher durability under acid and sulfate attack.

An experimental investigation has been carried out by Islam et al. [11] study the durability properties of sustainable concrete containing high volume palm oil waste materials namely oil palm shell (OPS) and POFA. POFA was used as partial cement replacement by 0%, 10%, 30% and 50% with water to binder ratio of 0.3. In the same way, POFA also replaced 0% and 70% of cement with water binder ratio of 0.4 and superplasticizer used was in the range 0.6% to 1.1% (by mass of binder) in order to maintain the slump within range. The compressive strength of POFA concrete was lower at 7 days and yet the strength of POFA concrete was higher at later ages. 10% POFA had higher strength gain at 90 days compared to the control concrete. The researchers also found that the water absorption and sorptivity of concrete containing a higher level of POFA were high.

Munir et al. [12] investigate the addition of POFA in producing the lightweight foamed concrete. The researchers carried out this study to evaluate the role of POFA in the foamed concrete production. This study has added the cement with 10%, 20%, 30%, 40% and 50% of POFA and used fixed water cement ratio which 0.5. With 50% addition of POFA in concrete, the compressive strength of concrete only decreased about 30 to 40% compared to control specimen. In the same way, 20% addition of POFA shows the acceptable strength of foamed concrete for non-structural purposes.

Mohammadhosseini et al. [13] studied the fresh and hardened state properties of SCC with 0%, 30% and 60% of POFA replacing cement in self-compacting concrete. Different water/cement ratios were used in this study which is 0.4, 0.45 and 0.5. Conclusion for fresh properties found that the increases of POFA as a cement replacement in SCC resulted in the lower workability with the acceptable range. The strength of the specimen was taken at 7, 28 and 90 days. The results found lower strength at an early age however the strength then increases at later ages. The strength of concrete at 30% replacement of cement almost achieved the same strength as control mix. Tensile and flexural strengths of SCC specimens show the similar trend with the compressive strength.

Awal et al. [14] determined the properties of concrete containing a high volume of POFA. This study had been done towards 50%, 60% and 70% replacement of cement with POFA with a variable water-cement ratio of 0.38, 0.42 and 0.48 and the addition of superplasticizer up to 2%. The researchers found that the workability of concrete is low with the high volume of POFA. However, the workability is improved to the satisfactory level with the addition of superplasticizer. In summary, the compressive and tensile strength of the concrete containing a high volume of POFA were found lower than control mix.

Ahmad et al. [15] present the compressive strength of POFA concrete. This study carried out with 5%, 10% and 15% of POFA as cement replacement with fixed water-cement ratio of 0.45. Compressive strength test was run on 3, 7, 28, 56 and 90 days. This research can be concluded that POFA concrete has higher workability than fly ash and quarry dust. However, the workability still decreases as the increases content of POFA. Moreover, 15% replacement of cement shows the optimum strength of concrete compared to others and the strength development of POFA has same patterns with OPC concrete. Table 1 shows the overall summary of previous study on POFA.

Table 1. Summary of previous work on POFA.

Authors & Year	Percentage of replacement	Application of material	Findings
Mohammadhosseini, et al., 2017	0% and 20%	Concrete	The addition of POFA in concrete resulted in lower workability. 20% POFA in concrete composite resulted in the decrease of drying shrinkage.
Ahamed & Siddiraju, 2016	0%, 5%, 7.5%, 10%, 12.5%, 15% and 17.5%	Concrete	12.5% cement replacement with POFA shows the increases in strength.
Alsubari et al., 2016	0%, 50%, 60% and 70%	Self-compacting concrete	Filling ability and passing ability are better than control. 70% of cement replacement was suggested to produce low-cost and sustainable concrete.
Ranjbar et al., 2016	0%, 10%, 15% and 20%	Self-compacting concrete	The increases of POFA content lead to the reduction in early mechanical properties but the final strength of SCC containing POFA was comparable.
Islam et al., 2016	0%, 10%, 30% and 50% 0% and 70%	Concrete	10% of POFA shows the higher compressive strength than control at the age of 90 days.
Munir et al., 2015	10%, 20%, 30%, 40% and 50% (Addition)	Lightweight foamed concrete	20% addition of POFA into foamed concrete shows the acceptable strength of foamed concrete for non-structural purposes.
Mohammadhosseini et al., 2015	0%, 30% and 60%	Self-compacting concrete	Replacement of POFA results in lower workability of concrete with acceptable range. Higher volume replacement of POFA shows the reduction in strength.
Awal & Abubakar, 2011	0%, 50%, 60% and 70%	Concrete	The strength of concrete containing a high volume of POFA shows the lower strength. Workability of high volume POFA low but improved with the addition of superplasticizer.

Ahmad et al., 2008	0%, 5%, 10% and 15%	Concrete	Workability shows a significant reduction with the increasing of POFA content. 15% of POFA replacement shows the optimum compressive strength and the same patterns of strength development with OPC concrete.

3. Ceramic waste in concrete production

Rani's idea [5] was replaced the cement with ceramic waste powder was explored. The researcher had studied the effect of replacement level towards the strength of the concrete. This study replaced cement by 0%, 10%, 20, 30%, 40% and 50% of ceramic waste with water-cement ratio of 0.4 for M-40 grade concrete. Results were taken at days 7, 28 and 56. The conclusion made by author stated that 10% replacement of cement shows the increases in compressive strength and further replacement level shows the decreases in compressive strength.

The aim of Kanaan and El-deib [16] was to investigate the effect of the replacement of cement with ceramic waste powder as an ingredient to sustainable concrete. Ceramic waste powder has improved the workability retention for concrete mixture M25. Strength test was run on 7, 28, 56 and 90 days and the data demonstrated that the replacement from 20% to 40% have lower strength improvement. The researchers found the highest strength improvement with 10% replacement. In summary, researchers mentioned that 10% replacement is suitable for strength improvement while 40% replacement suitable for durability improvement.

Arthi [17] has compared the concrete containing ceramic waste powder as cement replacement with conventional concrete. Proportions used in this study are 0%, 15%, 30%, 35%, 40% and 45%. The specimens were curing and tested at age 7, 21 and 28 days. Replacement level less than 35% by weight of cement increases the compressive strength while further replacement leads to decreases in strength. Moreover, the cost of production can decrease up to 25% with 35% ceramic waste powder as cement replacement.

Anwar et al. [18] investigated the effect of substitution the cement with ceramic waste powder and fine aggregate with waste marble powder. Proportions used in this study were 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% for both ceramic waste powder and waste marble powder for the production of concrete grade M-20. The strength was only tested on age 28 days. Conclusions draw from this study is the strength of the concrete gradually decreased with the increases of the replacement level of ceramic waste powder. So, it was recommended to replace the cement less than 30% due to it is not affecting the characteristic strength of M20 grade concrete.

Patel, Arora and Vaniya [6] presents the result of the use of ceramic waste powder in cement concrete with 0%, 10%, 20%, 30%, 40%, 50% and 60% of replacement level. The concrete was cast with 0.46 of water-cement ratio and sodium silicate was added up to 2%. Workability of concrete without the addition of sodium silicate shows the decreases of slump value. However, with the 10% and 40% replacement of cement shows the increases in slump value. The strength test was carried out at age 7, 14 and 28 days. The researchers recommend that 30% replacement of cement with the 2% addition of sodium silicate due to its achieved the optimum compressive strength. Moreover, tensile strength test recorded only 1% loss compared to conventional concrete.

Raval et al. [19] have conducted experimental investigation by 0%, 10%, 20%, 30%, 40% and 50% of ceramic waste powder as cement replacement with water-cement ratio of 0.52. To evaluate the mechanical properties, tests were carried out at age 7, 14 and 28 days. Replacement of cement with ceramic waste powder less than 30% recorded the increases in strength while more than 30% replacement level shows the decreases in strength.

Since the concrete is widely used in construction industry many studies have been conducted to implement and improve the quality of the concrete. Reuse of agricultural waste and industry waste to replace the cement material appears to be a solution for the pollution problem and high cost of building materials [20-21]. Summary of previous work on ceramic waste powder are shown in Table 2.

Table 2. Summary of previous work on ceramic waste powder.

Authors & year	Percentage of replacement	Application of material	Findings
Rani, 2016	0%, 10%, 20%, 30%, 40% and 50%	Concrete	10% of ceramic waste as cement replacement shows the increases of compressive strength.
Kanaan & El-dieb, 2016	0%, 10%, 20%, 30% and 40%	Concrete	Use of ceramic waste powder in concrete improved its workability retention. Replacement more than 10% shows the decreases in strength.
Arthi, 2016	0%, 15%, 30%, 35%, 40% and 45%	Concrete	Less than 35% replacement level shows the increases in strength while further replacement caused the strength decreases.
Anwar et al., 2015	0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%	Concrete	30% of ceramic waste powder is suggested due to it was not affecting the characteristic strength.
Patel et al., 2015	0%, 10%, 20%, 30%, 40%, 50% and 60%	Concrete	Slump value of mix without the addition of sodium silicate increase with 10% and 40% replacement. 30% volume of cement waste powder with 2% addition of sodium silicate shows the optimum strength of concrete.
Raval et al., 2013	0%, 10%, 20%, 30%, 40% and 50%	Concrete	Replacement less than 30% of concrete waste powder lead to the increases in concrete strength.

4. Conclusion

From the researchers discussed above, it is clearly shown that palm oil fuel ash and ceramic waste are suitable to use in the construction industry and more economic in the making of concrete. Palm oil fuel ash and ceramic waste are found to be suitable as a partial replacement of cement in concrete production. Most of the researchers suggested up to 20% replacement of palm oil fuel ash as a cement replacement in the concrete production. Replacement more than 20% leads to the decreases in the strength of concrete. For ceramic waste, the replacement suggested by the researchers is up to 30% and further replacement caused the decreases in the strength of concrete.

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