MANTECH Publications

Journal of Ceramics and Concrete Technology
Volume 8 Issue 3
ISSN No. 2457-0826 (Online)

A Review Article on Palm Oil & Fuel Fly Ash-Based Eco-Friendly Concrete Composite Sections

P. Guruswamy Goud[1], S.Priyanka[2], J.Anvesh[3], K.Prabhakar[4]

Assistant Professor [1,2,3,4]

Department of Civil Engineering

St. Martins Engineering College, Sec-500100 Telangana

***Corresponding Authors Email**: - guruswamygoud@gmail.com[1], sambari.priyanka93@gmail.com[2]*

Abstract

Concrete consumption has risen as a result of rapid global infrastructure development and increased material science, among other causes. Cement, an essential component of concrete, bonds the various solid components together to produce a cohesive mass. Cement manufacture produces a significant amount of greenhouse gases, accounting for about 10% of global carbon (IV) oxide (CO2) emissions. This, combined with a rise in environmental activism, has resulted in the creation of a number of novel solutions & supplementary cementitious materials. Palm oil fuel ash (POFFA) is a unique industrial byproduct that results from the burning of palm oil wastes in power plants for electricity generation. It is a highly reactive substance with strong pozzolanic tendencies and adequate micro-filling capacities. A review of concrete strength as influenced by the use of POFFA as a partial replacement for cement in concrete is offered in this research. The compressive strength of concrete as effected by the % replacement & fineness of POFFA in concrete is mainly explored here, based on data published in the literature on the utilization of POFFA in blended concrete. The benefits & drawbacks of POFFA in concrete are also discussed.

Keywords- *palm Oil, Fuel fly Ash; Concrete, Physical and Chemical Properties of POFFA, Fineness Effect of POFFA, Strength Development of Concrete*

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

INTRODUCTION

Global warming, climate variability, and, more frequently, the concept of environmental sustainability have all been key issues because of its negative consequences. The continuous introduction and accumulation of hazardous waste materials into the environment, as well as certain industrial operations that generate excessive amounts of greenhouse gases as by-products, sabotage efforts to create a cleaner environment . The building industry, in particular, is critical for rapid worldwide infrastructural development, given the steady increase in urbanisation and population expansion. The gross demand for cement, an essential component of concrete used in construction projects, and other associated materials, on the other hand, continues to rise at an exponential rate. Cement production is typically associated with a high use of natural resources and energy, as well as the emission of greenhouse gases . It is rightfully regarded as one of the most widely used commodities on the planet. It's also worth mentioning that 1 tonne of cement produces approximately 1 tonne of CO2 emissions. Cement manufacture appears to be responsible for 7–10% of global anthropogenic CO2 emissions; a close comparison with the aviation industry, which emits 2.8 percent CO2, reveals a three-fold lower volume of carbon (IV) oxide emissions. Alternative materials must be investigated if the exponential demand for cement is to be satisfied, as well as the need for ecologically sustainable solutions.

SCMs (supplementary cementitious materials) have gotten a lot of attention lately. There are a variety of natural and man-made silica-containing SCMs, and it's extremely crucial to employ waste from diverse sectors as these materials.

Palm oil fuel fly ash (POFFA) is a by-product of the combustion of palm oil wastes in oil mills; it has unique features and is a particularly reactive substance with significant pozzolanic tendencies .The use of oil palm solid wastes has been divided into five categories, as indicated in oil palm fronds, oil palm trunks, mesocarpfibre, empty fruit bunches, and palm kernel shell. Each component of palm solid wastes can be used for a variety of purposes. The tall-stemmed oil palm tree is classified as part of the Palmea family. This tree is grown in a number of countries, with Zaire, Nigeria, Malaysia, Indonesia, Ecuador, Colombia, and the Benin Republic, as well as Malaysia, dominating the production of palm oil-related items. According to reports from Malaysia, the total solid waste produced by over 200 oil mills annually is over ten million tonnes; as a consequence, the by-products are utilized as

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

alternative cheap sources of fuel to fire up palm oil mill boilers, resulting in a high volume of ash.

Applying industrial & agricultural wastes in concrete materials has displayed increasing trends & interest in terms of sustainability. Landfills are places where waste materials are disposed of indefinitely , and as the amount of waste materials increases, they are eventually dumped into the climate & cover a wider area of these landfills (example, municipal solid waste landfills, industrial waste landfills, hazardous waste landfills, & green waste landfills), resulting in a variety of environmental pollution issues. Landfill mining will provide significant benefits in terms of both environmental & economic issues. Organic wastes in concrete have superior qualities than cement in concrete, which has a higher carbon footprint. POFFA has been shown to use less energy during manufacture. In Malaysia, almost 1000 tonnes of POFFA were buried in landfills without being investigated for a second life. The use of palm oil fuel ash as a cement substitute can lower concrete production costs while simultaneously improving solid waste management and resulting in a cleaner environment.
POFFA is a type of ash that is produced by burning palm oil waste materials, usually kernel shell & husk. As is customary, excessive POFFA is disposed of in landfills, making proper land use increasingly difficult. It is vital to investigate its use in different industries in order to reduce potential environmental problems. In the 1990s, researchers began looking at the idea of using POFFA as a partial cement substitute for concrete, after finding a strength drop of 20 to 50 percent with a POFFA cement replacement of 10 to 50 percent. POFFA was discovered to be able to minimise sulphate attack as a result of the cement substitution.

The Palm Oil Fuel Fly Ash

Palm oil industries have the potential to play a significant role in the economic development of many tropical countries. During the processing of oil-palm fruit for oil extraction, these companies generate a substantial number of solid waste by-products, such as fibres, nut shells, & empty fruit bunches. With every 100 tonnes of fresh fruit bunches processed, the mill will discharge around 20 tonnes of nut shells, 7 tonnes of fibres, and 25 tonnes of empty bunches (Tay, 1995). POFFA (palm oil fuel ash), which accounts for roughly 5% of all solid waste, has the potential to be utilised as pozzolanic materials in the concrete industry (Sata, 2010). It is the ash created by the burning of palm oil fibre and shell for energy generation in palm oil mills. It's a promising pozzolanic that's widely distributed around the world. POFFA

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

refers to the byproducts of the palm oil industry, such as palm oil residue, palm fibre, and shells, which are burned at temperatures ranging from 800 to 10,000 degrees Celsius to generate steam for electricity generation in biomass thermal power plants (Tangchirapat, 2009). More than 100,000 tonnes of POFFA are generated in Thailand each year (Chindaprasirt, 2007), and this number is growing every year because palm oil is one of the main raw materials utilized in biodiesel production. Because of its high silica content, it has only lately been acknowledged as a pozzolanic material in concrete. Several pozzolanic materials, like silica fume & fly ash, are similar to this one. POFFA, on the other hand, is utilised not only as a cement substitute but also in the construction of strong and long-lasting concrete due to its pozzolanic qualities (Awal, 1997).

Physical & Chemical Properties of POFFA

Various forms of agricultural waste have different physical & chemical qualities that, with careful selection, could be used in concrete. Table 1 shows the chemical composition & physical features of various POFFA utilized in various research studies. POFFA is mostly composed of SiO2, which accounts for more than half of its chemical composition. The total amount of SiO2, Al2O3, and Fe2O3 in most of the ashes was less than 70%, although ASTM C618 (ASTM, 2001). This should be at least 70% for class N pozzolan, according to the specification. The chemical composition of all of these ashes is nearly identical. POFFA is significantly finer than OPC, as shown in this table. Based on the chemical analysis, all of the POFFA met the pozzolana requirement in general and may be classified as class C pozzolans according to ASTM C618 (ASTM, 2001). Other studies have also recommended this class (Chindaprasirt, 2007; Tay, 1990). Figure 2 depicts the particle size distribution of OPC, Fly ash (OFA), Palm oil fuel ash (GPOA), & Ground rice bark ash (GRBA). This image illustrates that after grinding, the POFFA has a grading curve that is comparable to that of the OPC. As demonstrated in Table-1, the grinding procedure enhanced the fineness & specific gravity of POFFA. This occurred as a result of the crushing of porous particles with low specific gravity into smaller particles with decreasing porosity (Cheerarot, 2004). Other investigators who ground fly ash & bottom ash came to the same conclusion (Kiattikomol, 2001; Isaia, 2003).

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

Fineness Effect of Poffa on Concrete Strength

The fineness of POFFA & cement has an impact on concrete strength. A higher fineness of POFFA can generate stronger concrete strength and also better performance against sulphate attack for the same replacement of POFFA in concrete with varying fineness (Tangchirapat, 2007). Researchers discovered that as the fineness of POFFA is reduced, the depth of carbonation increases, i.e., when high fineness POFFA is utilised, the carbonation drops (Rukzon, 2009). The fineness of POFFA has a significant impact on concrete's sulphate resistance. Ungrounded POFFA has a low pozzolanic reaction, making it unsuitable for use as a cement substitute in concrete. As a result, the concrete has low compressive strength and sulphate resistance (Jaturapitakkul, 2007). When a high fineness of POFFA (1.0 percent retained on a No. 325 sieve) was used as a cement replacement at a level of 10% & 20% in concrete, the compressive strength was 100 percent and 99 percent at 28 days, correspondingly, compared to concrete made with OPC type I cement (Jaturapitakkul, 2007). Tangchirapat et al. looked into the influence of fineness on the strength of concrete, as seen in. (Tangchirapat, 2007). They discovered that when original ash (OP) was replaced by 20-40%, the compressive strengths of concretes at 28 days is around 31% & 66% of those prepared with OPC type I cement. Concrete's compressive strength was reduced as a result of big POFFA particles with high porosity, which increased the water-to-binder ratio. As a result, the original size of POFFA is not acceptable for use as a cement substitute in concrete. At the ages of 28 and 90 days, he found that the compressive strengths of concrete (produced with median particle size 15.9m of POFFA) were 30.1 and 37.6MPa, or around 94 percent and 101 percent of OPC type I concrete (control concrete) (Figure. 3b). The pozzolanic reaction contributes to the development of compressive strength. As shown in Fig. 2b, the concrete containing 20% POFFA had a compressive strength of 26.9 MPa, or 84 percent of the control concrete, after 28 days, and climbed to 33.4 MPa, or 90 percent of the control concrete after 90 days. At the greatest fineness of POFFA (median particle size 7.4 m) employed in that investigation, it was discovered that the compressive strengths of the POFFA-replaced concrete were as high as the control concrete at 28 days. At 28 and 90 days, the compressive strengths of concretes with 10% and 20% POFFA replacement were 31.9, 31.6, and 39.0, 38.6 MPa, respectively, or around 100 percent, 99 percent, and 105 percent, 104 percent of the control concrete. Furthermore, at 90 days, the compressive strength of concrete with 30% POFFA substitution was 36.8 MPa, which was nearly identical to the control concrete. The higher the fineness of POFFA, the better the pozzolanic reaction and

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

the small particles may also fill up the spaces of the concrete mixture, resulting in improved concrete compressive strength. POFFA was employed as a replacement for Portland cement type I at a level of 10-40% by weight of binder in concrete production by Isaia et al. (Isaia, 2003) and Jaturapitakkul et al. (Jaturapitakkul, 2007) in varied particle sizes: small, medium, and big. They found that big particle size is not acceptable for use as a cement replacement in concrete because it provides poor compressive strength, but that medium & small particle size of all POFFA mixes produce strength results that are similar to OPC at 28 days. As a result, all of these concrete compressive strength tests show that when ground to a fine particle size, POFFA accomplishes as a highly potential pozzolanic material in concrete; additionally, the optimum replacement of POFFA by weight of binder is around 20% - 30%, without sacrificing concrete compressive strength.

Properties of Oil Palm Shells as Construction Materials

Properties	**Oil Palm Shells**
Specific gravity	1.16–1.37
Bulk density (uncompacted) (kg/m3)	512–553
Void ratio (compacted) (%)	55
Void ratio (uncompacted) (%)	62
Absorption of water at 24 h (%)	21-29
Flakiness index (%)	65
Value of aggregate crushing (%)	6-11

Supplementary Usage of POFFA in Cement & Concrete

For more than a decade, POFFA has been employed as a supplemental material in concrete. Using agricultural wastes such as POFFA as aggregate or cement replacement material in concrete provides both engineering & financial benefits. POFFA, ground to an appropriate fineness, has been used as a pozzolanic material to generate high-strength concrete with a 90-day strength of 100 MPa (Awal, 1997; Jaturapitakkul, 2007; Sata, 2007). The usage of blended pozzolans containing an equivalent amount of POFFA & FA, as well as RHA & FA, can improve mortar strength & resistance to chloride penetration in concrete (Chindaprasirt, 2008). Oil palm shell (OPS) has been utilised as a coarse aggregate in concrete and has been proven to be helpful as structural lightweight concrete; the compressive strengths of OPS concrete range from 20 to 24 MPa for 28 days, which meets the strength requirements of

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

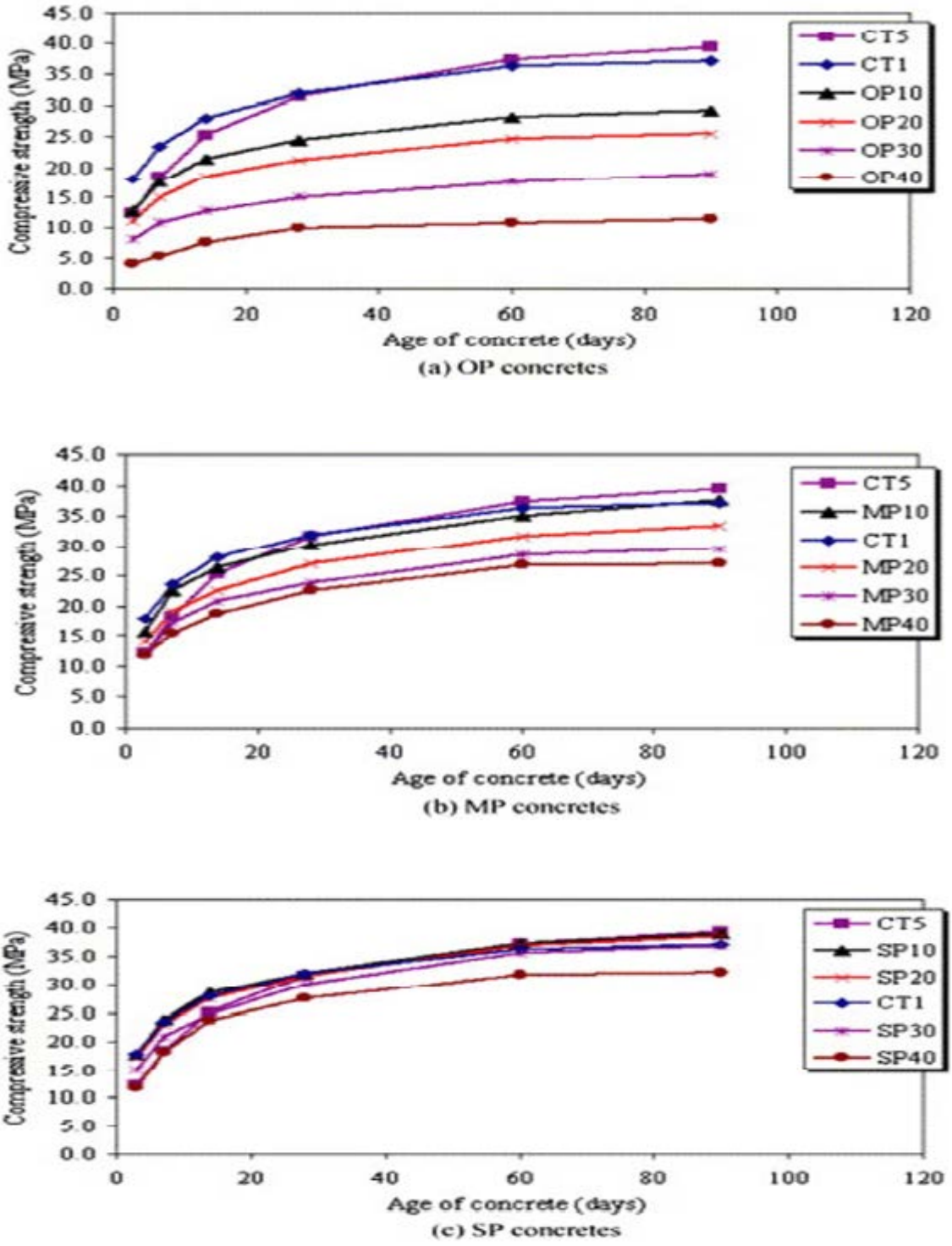
structural lightweight concrete (Mannan, 2001). The POFFA was researched by Chindaprasirt et al. (Chindaprasirt, 2007) to see if it could be used as a new pozzolanic material in concrete with acceptable strength. They added that the optimum cement replacement by POFFA is 20%; beyond this ratio, compressive strength is diminished and concrete permeability increases. The development of concrete strength could be influenced by a 50 percent POFFA replacement amount of cement (Awal, 1997).

Aggregate could be used to build low-cost dwellings, farm structures, tennis courts, pavements, blocks, and paving drains, resulting in lower production costs (Mannan, 2002). This ash contains pozzolanic qualities that allow it to not only replace cement but also perform a key role in the creation of strong & long-lasting concrete (Eldagal, 2008). To manufacture high-strength concrete, POFFA was utilised to replace Portland cement, ASTM Type I, by 10, 20, and 30% by weight of cementitious ingredients (Mannan, 2001). Ground POFFA with a high fineness can be used to make high-strength concrete instead of cement. Concretes with 10-30% fine POFFA had stronger compressive strength than concrete prepared with Type I Portland cement after 28 days. When compared to high-strength concrete manufactured with Type I Portland cement, the use of POFFA in high-strength concrete resulted in a small reduction in concrete drying shrinkage, depending on the amount of POFFA applied (Tangchirapat, 2009). As a result, POFFA, a waste material with strong pozzolanic properties, must be employed as a better supplemental cementing ingredient in concrete, with finer selection & appropriate alternative percent.

POFA concrete times of setting

Percentage of Replacement of POFA, %	**Early Setting Time, Min**		**Final Setting Time, Min**	
	Ground POFA	**Un ground POFA**	**Ground POFA**	**Un ground POFA**
0	251	125	392	1945
10	256	130	398	223
20	267	140	421	238
30	275	150	435	240
40	291	155	440	248

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved



Figures: Relationship amongst compressive strength & age of concretes.

[Note: CT1 and CT5, control concretes made from Portland cement Type I and Type V, respectively. OP, MP, and SP, are the original, medium, and small sizes of palm oil fuel ash (POFFA). 10, 20, 30, and 40, percent replacement of POFFA in Portland cement Type I by weight of binder].

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

Strength Development of Concrete with POFFA

The strength development of POFFA mixed concrete differs significantly from that of OPC concrete. Due to the extended hydration process of POFFA, blended concrete with POFFA shows a slower strength gaining tendency than OPC concrete at early ages. POFFA particles' fineness fills the spaces between cement and the aggregates. As a result, the compressive strength of POFFA concretes improves with time. Ca (OH)2 is produced during the cement hydration process, which reacts with the SiO2 in POFFA. As a result of the increased calcium silicate hydrate generated during this process, interfacial bonding between aggregates and pastes is improved at later ages.

These features have been found to boost the density & compressive strength of concrete (Isaia, 2003). Figure shows the impact of POFFA on the compressive strength of concrete. Tangchirapat et al. (Tangchirapat, 2009) replaced Type I Portland cement with 10-30% POFFA at an early age of 7 days and discovered that the compressive strength was comparable to concrete built with OPC Type I cement.

The compressive strength of POFFA mixed concrete is higher than that of OPC concrete, as shown by this result. The compressive strength of concrete containing 20% POFFA is higher than that of OPC concrete, according to Chindaprasirt et al. (Chindaprasirt, 2007). The compressive strength of concrete containing 20% POFFA is lower than that of OPC concrete as the replacement percent increases. POFFA concrete has a lower concrete strength than OPC concrete for a 40 percent replacement. Furthermore, as shown in Fig., POFFA could be used to replace up to 30% of the cement in high-strength concrete, & compressive strength produced is higher than that of high-strength concrete manufactured with Type I Portland cement. As shown in Figure. a 20 percent replacement of POFFA could be the ideal amount for the manufacturing of concrete because concrete strength gradually decreased beyond this level of replacement. These findings imply that finely ground POFFA is a reactive pozzolanic material that could be employed as a mineral admixture in the production of high-strength concrete up to a point (about 20-30 percent).

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

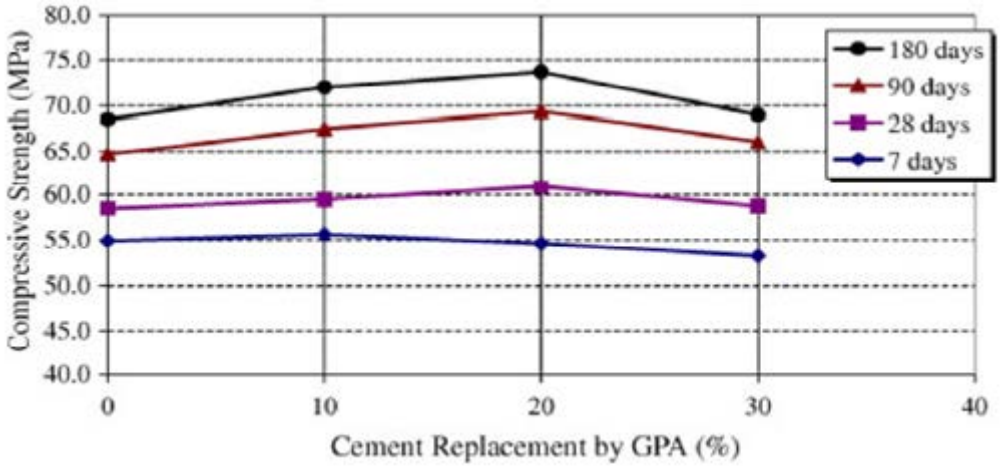


Figure: Correlation among strength & cement replacement by (POFFA) GPA

Benefits

POFFA has been shown to have good pozzolanic reactivity in various studies and it also contributes to the production of denser and more durable concrete with a specific level of replacement the following benefits of POFFA for usage in cement or concrete have been discovered:

- Using POFFA in concrete could lower the cost of concrete production by reducing the amount of cement used, as well as reducing the disposal problem.
- When compared to concrete created with OPC type I cement, POFFA could be utilised as a cement replacement to produce high-strength concrete because of its fineness; it also minimises water permeability and has a lower degree of expansion & loss in compressive strength.
- POFFA could be used as pozzolans to replace a portion of Portland cement in the production of mortars with high strength & resistance to chloride penetration.
- In comparison to conventional concrete, concrete employing high fineness POFFA (retained 1% on a No. 325 screen) as a 20-30% replacement reached 100 percent strength.
- Palm oil shell concrete could be used as a structural light weight concrete (Basri, 1999; Mannan, 2001). POFFA, according to Awal&Hussin (Awal, 1997), has a good potential for reducing expansion caused by the alkali-silica reaction.
- POFFA could be utilised as a cement substitute to provide excellent resistance against sulphate attack.
- The temperature rise of fresh concrete with POFFA decreased as the POFFA content rose (Sata, 2010).

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

DRAWBACKS

POFFA's use in cement or concrete has a number of engineering, financial, & environmental advantages that have already been discussed in this study. Despite these positive effects of POFFA in concrete, it also has certain negative impacts, which are listed below:

- When compared to OPC concrete, the use of POFFA in concrete has a comparatively significant carbonation impact.
- As Portland cement was replaced with POFFA, the water requirement in concrete mixtures increased when compared to OPC concrete.
- Concrete's strength is greatly reduced when more than 30% of it is replaced; at a young age, strength is slowly gained.
- The original coarse POFFA (lower fineness) does not help to improve concrete strength.

CONCLUSION

This study evaluation, the following conclusions about POFFA in mortar/concrete can be made. POFFA as a PCR in concrete mixes will alleviate the challenges of agro-based waste disposal and related environmental issues, reduce the ecological vulnerabilities of ordinary Portland cement plants, & reduce greenhouse gas (CO2, methane, CO, etc.) emissions in the atmosphere to a significant extent while lowering the overall cost of cement usage. POFFA's application in concrete is critical because of their fresh and hardened qualities. The fineness of POFFA is a significant feature in concrete, according to this review. POFFA has a strong pozzolanic property. As a result, its integration in cement or concrete may be able to help meet the need for cement. When compared to OPC concrete, concrete made with a specific level of POFFA substitution had the same or higher strength. Up to around 30% replacement of POFFA, there is no notable reduction in concrete strength. As a result, efficient use of POFFA in cement or concrete production will be a significant cement and energy saving step forward for the current social need in the concrete sector. Effective POFFA consumption in cement or concrete is a present critical issue for waste disposal, ecological environment control, and long-term concrete production for the world's future generations.

REFERENCES

1. Chotetanorm, C.; Chindaprasirt, P.; Sata, V.; Rukzon, S.; Sathonsaowaphak, A. High-Calcium Bottom Ash Geopolymer: Sorptivity, Pore Size, and Resistance to Sodium Sulfate Attack. J. Mater. Civ. Eng. 2013, 25, 105–111. [CrossRef]

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

2. Awal, A.; Hussin, M. The effectiveness of palm oil fuel ash in preventing expansion due to alkali-silica reaction. Cem. Concr. Compos. 1997, 19, 367–372. [CrossRef]
3. Chindaprasirt, P.; Homwuttiwong, S.; Jaturapitakkul, C. Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. Constr. Build. Mater. 2007, 21, 1492–1499. [CrossRef]
4. Tay, J. Ash from Oil-PalmWaste as a Concrete Material. J. Mater. Civ. Eng. 1990, 2, 94–105. [CrossRef]
5. Kroehong,W.; Sinsiri, T.; Jaturapitakkul, C. Effect of Palm Oil Fuel Ash Fineness on Packing Effect and Pozzolanic Reaction of Blended Cement Paste. Procedia Eng. 2011, 14, 361–369. [CrossRef]
6. Awal, A.S.M.A and M.W. Hussin, 1997. The Effectiveness of Palm Oil Fuel Ash in Preventing Expansion due to Alkali-silica Reaction. Cement and Concrete Composite, 19(4): 367-372.
7. ASTM, C., 618, 2001. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete, ASTM C618–00, Annual Book ASTM Standard 04.02, 2001: 310-313.
8. Basri, H.B., M.A. Mannan and M.F.M. Zain, 1999. Concrete Using Waste Oil Palm Shells as Aggregate. Cement and Concrete Research, 29: 619-622.
9. Chindaprasirt, P., S. Homwuttiwong and C. Jaturapitakkul, 2007. Strength and Water Permeability of Concrete Containing Palm Oil Fuel Ash and Rice Husk-Bark Ash. Construction and Building Material, 21: 1492-1499.
10. Chindaprasirt, P., S. Rukzon, V. Sirivivatnanon, 2008. Resistance to Chloride Penetration of Blended Portland Cement Mortar Containing Palm Oil Fuel Ash, Rice Hush Ash and Fly Ash. Construction and Building Material, 22(5): 932-938.
11. Cheerarot, R. and C. Jaturapitakkul, 2004. A Study of Disposed Fly Ash from Landfill to Replace Portland Cement. Waste Management, 24(7): 701-709.
12. Eldagal, O.E.A., 2008. Study on the Behaviour of High Strength Palm Oil Fuel Ash (POFFA) Concrete. M. Engineering Thesis (Civil and Structure), UniversitiTeknologi Malaysia, Malaysia.
13. Isaia, G.C., A.L.G. Gastaldini and R. Moraes, 2003. Physical and Pozzolanic Action of Mineral Additions on the Mechanical Strength of High-Performance Concrete. Cement and Concrete Composite, 25: 69-76.

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

14. Jaturapitakkul, C., K. Kiattikomol, W. Tangchirapat and T. Saeting, 2007. Evaluation of the Sulfate Resistance of Concrete Containing Palm Oil Fuel Ash. Construction and Building Material, 21(7): 1399-1405.
15. Kiattikomol, K., C. Jaturapitakkul, S. Songpiriyakij and S. Chutubtim, 2001. A study of Ground Coarse Fly Ashes with Different Finenesses from Various Sources as Pozzolanic Materials. Cement Concrete Composite, 23(4-5): 335-343.
16. Mannan, M.A. and C. Ganapathy, 2001. Long-term Strengths of Concrete with Oil Palm Shell as Coarse Aggregate. Cement and Concrete Research, 31: 1319-1321.
17. Mannan, M.A. and C. Ganapathy, 2004. Concrete from an Agricultural Waste-Oil Palm Shell (OPS). Building and Environment, 39: 441-448.
18. Mannan, M.A. and C. Ganapathy, 2002. Engineering Properties of Concrete with Palm Shell as Coarse Aggregate. Construction and Building Materials, 16: 29-34.
19. Rukzon, S., P. Chindaprasirt, 2009. Strength and Chloride Resistance of Blended Portland Cement Mortar Containing Palm Oil Fuel Ash and Fly Ash. International Journal of Minerals, Metallurgy and Materials, 16(4): 475-481.
20. Sata, V., C. Jaturapitakkul and R. Chaiyanunt, 2010. Compressive Strength and Heat Evolution of Concretes Containing Palm Oil Fuel Ash. Journal of Materials in Civil Engineering, 22(10): 1033-1038.
21. Sata, V., C. Jaturapitakkul and K. Kiattikomol, 2007. Influence of Pozzolan from Various By-product Materials on Mechanical Properties of High-strength Concrete. Construction and Building Materials, 21(7): 1589-1598.
22. Tangchirapat, W., C. Jaturapitakkul and P. Chindaprasirt, 2009. Use of Palm Oil Fuel Ash as a
23. Supplementary Cementitious Material for Producing High-strength Concrete. Construction and Building Materials, 23(7): 2641-2646.
24. Tay, J.H. and K.Y. Show, 1995. Use of Ash Derived from Oil-Palm Waste Incineration as a Cement Replacement Material. Resources, Conservation and Recycling, 13: 27-36.
25. Tangchirapat, W., T. Saeting, C. Jaturapitakkul, K. Kiattikomol and A. Siripanichgorn, 2007. Use of Waste Ash from Palm Oil Industry in Concrete. Waste Management, 27: 81-88.
26. Tay, J.H., 1990. Ash from Oil-Palm Waste as Concrete Material. Journal of Materials in Civil Engineering, 2(2): 96-105.

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved

27. Amran, Y.M.; Alyousef, R.; Alabduljabbar, H.; El-Zeadani, M. Clean production and properties of geopolymer concrete; A review. J. Clean. Prod. 2020, 251, 119679. [CrossRef]
28. Amran, M.; Murali, G.; Fediuk, R.; Vatin, N.; Vasilev, Y.; Abdelgader, H. Palm Oil Fuel Ash-Based Eco-Efficient Concrete: A Critical Review of the Short-Term Properties. Materials 2021, 14, 332. [CrossRef] [PubMed]
29. Amran, M.; Debbarma, S.; Ozbakkaloglu, T. Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-termdurability properties. Constr. Build. Mater. 2021, 270, 121857. [CrossRef]
30. Fediuk, R.; Amran, Y.M.; Mosaberpanah, M.; Danish, A.; El-Zeadani, M.; Klyuev, S.; Vatin, N. A Critical Review on the Properties and Applications of Sulfur-Based Concrete. Materials 2020, 13, 4712. [CrossRef]
31. Production, S.W.M.C. Global Cement Production Top Countries 2017, Major Ctries. Worldw. Cem. Prod. from 2012 to 2017. 2019. Available online:www.statista.com/statistics/267364/world-cement-production-by-country/ (accessed on 13 March2021).
32. Nasvi, M.; Ranjith, P.; Sanjayan, J.; Bui, H. Effect of temperature on permeability of geopolymer: A primary well sealant for carbon capture and storage wells. Fuel 2014, 117, 354–363. [CrossRef]
33. Johnson, M.E.; Gonzalez, A. Estimating Cost Savings for Aviation Fuel and CO2 Emission Reductions Strategies. Coll. Aviat. Rev. Int. 2013, 32, 79–102. [CrossRef]

Page 114-127 © MANTECH PUBLICATIONS 2023. All Rights Reserved