

# SPENT BLEACHING EARTH AS VALUE-ADDED MATERIAL TO MATERIAL CONSTRUCTION APPLICATIONS: A REVIEW

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## ABSTRACT

Crude palm oil (CPO) serves as a significant export commodity for Indonesia, contributing positively to the country's economic growth and generating income for communities. Nonetheless, the production of CPO results in an environmental drawback in the form of refined, bleached and deodorised (RBD) palm oil, which poses environmental concerns. One pivotal material used in the purification process to transform the reddish-orange CPO into a lighter yellow hue is known as bleaching earth. As a consequence, a substantial amount of waste, referred to as spent bleaching earth (SBE), is generated and recovered to prevent harm to the environment. Remarkably, research has revealed that SBE exhibits pozzolanic properties, rendering it suitable for incorporation into construction materials. The primary objective of this study is to emphasise the advantages of integrating SBE into the construction material manufacturing process. Mixtures containing eco-process pozzolan (EPP), the product derived from SBE, have exhibited superior strength characteristics when compared to mixtures using ordinary portland cement (OPC). Furthermore, concrete incorporating pozzolan mixtures has displayed increased strength values when subjected to high temperatures, outperforming concrete made exclusively with OPC. However, further investigation is required to ascertain the thermal resistance capabilities of EPP as a component in mortar or concrete.

**Keywords:** concrete, crude palm oil, eco process pozzolan, mortar, spent bleaching earth.

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## INTRODUCTION

The economies of Indonesia and Malaysia are significantly supported by the palm oil industry. It has not only created income opportunities for individuals and generated employment within the palm oil sector but has also served as a catalyst for economic activity, tax revenue generation, and the augmentation of foreign exchange reserves (Begum *et al.*, 2019; Dey *et al.*, 2020; Maksum *et al.*, 2021; Mareeh *et al.*, 2022). Notably, the area dedicated to oil palm plantations in Indonesia experienced significant growth from 2018 to 2022, with an expansion of land totalling 1.01 million hectares.

Additionally, crude palm oil (CPO) production surged to 3.94 million tonnes from 2018 to 2022. Table 1 presents data on CPO production and oil palm plantations in Indonesia from 2018 to 2022.

**TABLE 1. INDONESIA CPO PRODUCTION AND OIL PALM PLANTATION FROM 2018-2022**

Year	CPO production (million tonnes)	Oil palm plantation (million hectares)
2018	42.88	14.33
2019	47.12	14.46
2020	45.74	14.59
2021	45.12	14.62
2022	46.82	15.34

Source: Badan Pusat Statistik Indonesia (2023).

Malaysia, like Indonesia, is one of the greatest palm oil producers in the world, with 5.74 million hectares of oil palm plantations and approximately 18 million tonnes of CPO produced in 2021 (Parveez *et al.*, 2022).

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The process of refining CPO into refined, bleached and deodorised (RBD) palm oil requires bleaching earth as a colour-removing agent. After use, bleaching earth becomes a by-product of this process. The use of bleaching earth is proportional to the amount of RBD palm oil produced. The larger the volume of RBD palm oil produced, the greater the amount of bleaching earth needed, consequently, this affects the amount of SBE produced, resulting in an escalation.

The eco process prozzolan (EPP), or solid extraction from spent bleaching earth (SBE), has pozzolanic characteristics. Recent developments have highlighted the growing utilisation of EPP as a component in blended cement production. Although research on EPP as a pozzolanic material is limited, waste products with pozzolanic characteristics are being used in concrete as cement substitutes. This approach aims to minimise the use of traditional cement, thereby reducing the release of CO<sub>2</sub> associated with cement production.

Cement plants were responsible for a significant contribution of 2.9 billion tonnes of CO<sub>2</sub> emissions all over the world in 2021, according to the data that is currently available (Kaptan *et al.*, 2024). However, in 1990, the level of CO<sub>2</sub> emissions that was documented was 0.57 billion tonnes (Benhelal *et al.*, 2021). The emission of CO<sub>2</sub> during the manufacturing of 1 t of Portland cement is predicted to range from 0.73 to 0.99 t throughout various geographical regions (Zhu, 2011). It can be asserted that the manufacturing of 1 kg of Portland cement results in the emission of about 1 kg of CO<sub>2</sub> into the atmosphere (Adesina, 2020).

By incorporating pozzolanic materials like EPP in concrete, the reliance on cement can be reduced, resulting in lower CO<sub>2</sub> emissions. The use of EPP as a pozzolanic material offers an environmentally friendly solution to decrease the carbon footprint associated with the cement industry. By utilising waste products with pozzolanic characteristics, the goal is to create more environmental-friendly concrete mixtures and contribute to the reduction of CO<sub>2</sub> emissions in the cement manufacturing process.

### CPO as Raw Material for RBD Palm Oil

CPO is a vegetable oil that contains solid triacylglycerides or triacylglycerols, as well as various other components including lipases, free fatty acids (FFA), pigments, phosphatides, partial glycerides, colouring agents and carotene. The yellow and red colour in CPO is caused by the intensity of carotenoid pigments. These pigments not only affect the colour of the CPO but can also impact the clarity level of the CPO (Ifa *et al.*, 2021).

CPO is produced through a series of procedures within the palm oil production process. Palm oil can

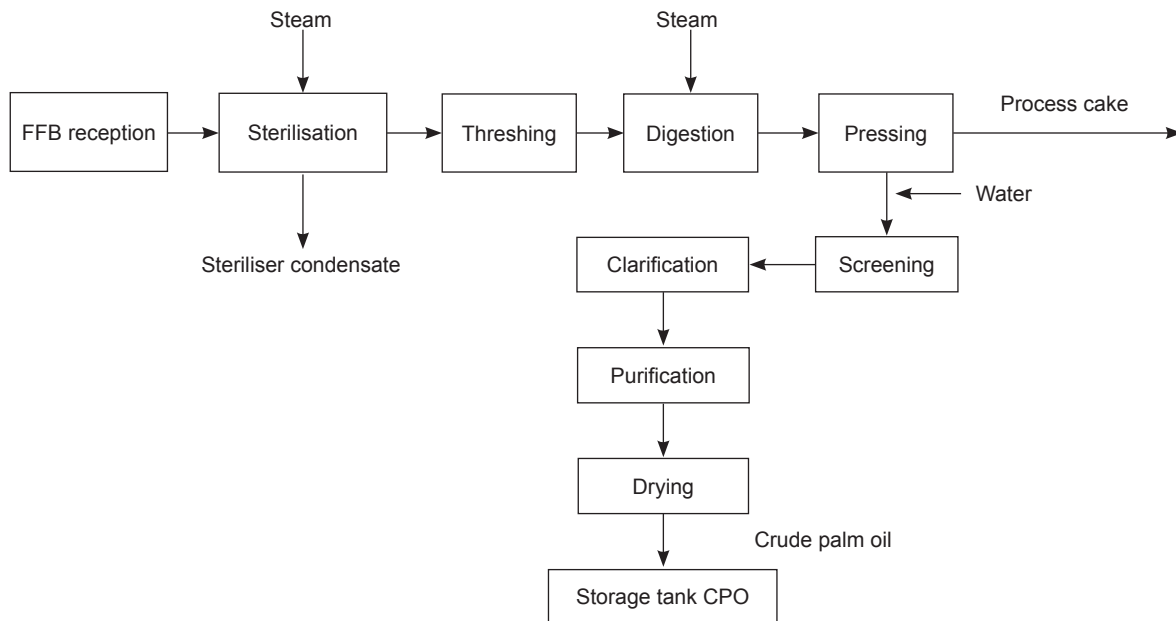
also undergo fractionation, a process that separates it into two distinct forms: Olein (liquid) and stearin (solid). Cooking oil and frying oil typically use olein as their base ingredient, while stearin is commonly employed in food processing and solid fat compositions (Hong, 2023).

In *Figure 1*, the production of palm oil begins with the processing of oil palm crops. Upon arrival at the palm oil mill, fresh fruit bunches (FFB) go through several stages, including reception, sterilisation, threshing, digestion, pressing, clarification, purification and kernel recovery. Before being placed into the hopper and cage to start the process of FFB into CPO, FFB are first examined for their level of ripeness and characteristics. The quality of FFB can be distinguished by observing the ripeness degree of the FFB, in which a ripe FFB should have an OER of at least 21% and FFA less than 5% (Sharif *et al.*, 2017). FFB are then placed into a horizontal steriliser using cages and subjected to a specific temperature and pressure for several minutes, following the standards set by the factory (Hong, 2023). This sterilisation process halts the enzymatic process, preventing an increase in the FFA content and conditions the palm kernel to reduce cracking during subsequent processing.

Following sterilisation, the threshing process is employed to separate the steamed fruit from the bunch, preparing it for further processing. Digestion comes next, breaking down the oil cells before the extraction and separation of the mesocarp from the kernel. The pressing process is then utilised to extract oil from the digested palm fruit. A screw press is used to squeeze the mashed and chopped fruit fibre from the digester, yielding crude oil. This oil product consists of a blend of solids and a cake comprising kernels and fibre.

Subsequently, the clarification stage takes place. At this point, approximately 60% of the extracted crude oil is oil, 24% is water and 10% is non-oil solids (NOS). The coarse contaminants in crude oil are separated by diluting the oil with hot water and passing it through a vibrating screen. Following this step, the purified oil undergoes clarification in a vertical settling tank or clarifier. Within this tank, the different phases naturally segregate due to gravity. The oil rises to the top and is skimmed off before undergoing purification through a high-speed centrifuge to eliminate any remaining impurities. Finally, CPO is transferred into a storage tank before it is dispatched to refineries for further processing.

One effective strategy for enhancing the value of palm oil products is to transform them into oleochemical products. Currently, the oleochemical industry offers substantial market opportunities, with global demand for oleochemicals exceeding supply by approximately 290,000 t (Fajarika *et al.*, 2023).



Source: Hong (2023).

Figure 1. Process production of CPO.

Beyond its conventional applications as a vegetable oil in the food industry and for biodiesel production, CPO boasts properties that are particularly beneficial to the health sector, notably the pharmaceutical industry. Notably, tocotrienol, a potent antioxidant found in palm oil, strengthens the immune system and complements the components of vitamin A and E. Palm oil comprises various components that promote human health, including alpha-carotene, beta-carotene, gamma-carotene, sources of vitamin E (tocopherol, tocotrienol), lutein, sterols, unsaturated fatty acids and ubiquinone (Rada-Bula *et al.*, 2023).

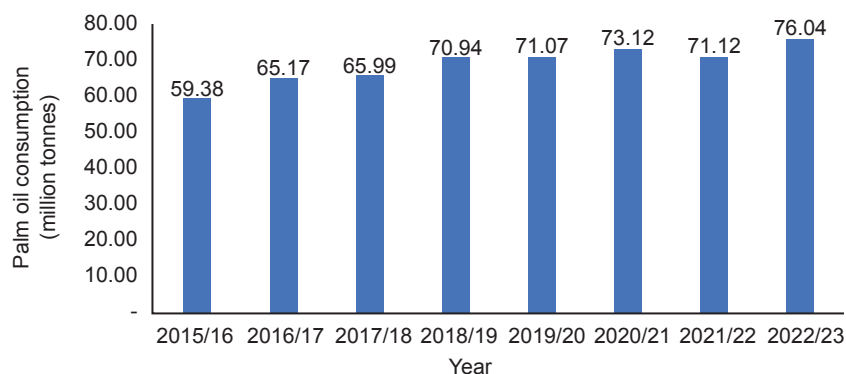
Alpha-carotene reduces the risk of liver, lung, pancreas and stomach cancers, while beta-carotene helps in lowering the risk of heart disease and maintaining eye health. Lutein contributes to a reduced risk of epithelial cancer and cataracts, while ubiquinone aids in enhancing the immune system, preventing heart disease and hypertension, and safeguarding red blood cells from oxidative damage. All of these components underline the multitude of benefits that palm oil offers to the pharmaceutical industry (Alfin, 2021).

In addition to the pharmaceutical sector, palm oil finds extensive use in the cosmetics industry due to its vitamin E content. Palm oil assists in maintaining smooth skin, eliminating acne and promoting healthy hair. It is a suitable remedy for dry and dandruff-prone hair. Utilising natural substances like palm oil in cosmetics is considered a safer and more organic alternative to synthetic skincare products. While CPO, obtained through palm fruit processing, contains several health-beneficial

components, additional processing is required to fully harness its benefits (Alfin, 2021).

Approximately 60% of the global vegetable oil trade and 25% of worldwide consumption are attributed to palm oil, making it one of the most widely produced vegetable oils globally. Palm oil used globally 24% to serve industrial purposes, while 74% is employed in food products. Figure 2 illustrates the demand for palm oil over the past few years (Shahbandeh, 2023).

Nonetheless, the production of CPO often faces scrutiny due to its emission of greenhouse gases (GHG) and other sustainability concerns. The primary greenhouse gases in earth's atmosphere include carbon dioxide, methane, nitrous oxide and hydrofluorocarbons (Matthew, 2023). Recognising the importance of addressing global climate change, Indonesia and Malaysia, the world's top two palm oil producers, have made substantial efforts to adopt sustainable practices in palm oil production and improve their carbon efficiency. To achieve this objective, both countries have initiated programmes to repurpose waste generated from palm oil processing. Various measures have been implemented, including the utilisation of waste as biomass derived from palm kernel shells, empty fruit bunches, and fibre. The palm oil industry produces substantial quantities of these by-products, presenting opportunities for their conversion into biodiesel, bioenergy, industrial materials, composting, animal feed production and the efficient utilisation of palm oil waste residues (Cheah *et al.*, 2023; Gani *et al.*, 2023). Life cycle assessments have also been conducted to evaluate the environmental



Source: Shahbandeh (2023).

Figure 2. Palm oil consumption worldwide.

impact of CPO production (Chuen & Yusoff, 2012; Nijaya *et al.*, 2008). Substantial endeavours have been undertaken to enhance the sustainability of the oil palm industry, focusing on environmental, social and economic aspects.

### Bleaching Earth as Bleaching Material

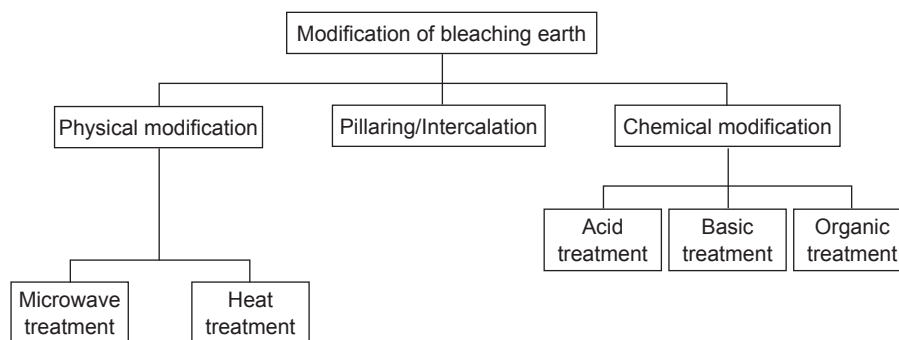
Bleaching earths typically comprise up to three distinct types of clay minerals with varying compositions: Bentonite, attapulgite, and sepiolite. These clay minerals consist of aluminium silicate crystals ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ), bound water, alkali metals [such as calcium oxide ( $\text{CaO}$ ) and magnesium oxide ( $\text{MgO}$ )] and other transition metals [e.g., iron oxide ( $\text{Fe}_2\text{O}_3$ )], represented by the formula  $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot n\text{H}_2\text{O}$  (Ashari *et al.*, 2017).

The remarkable capacity of bleaching earth to adsorb colourants and other undesirable components during the production of edible oil is due to this composition (Jumaah *et al.*, 2019). This feature makes it an invaluable resource in the edible oil production process, whether it is natural or activated bleaching earth. The goal is to enhance various aspects of the final products, including their overall quality, flavour, aroma and consistency. Factors such as particle size distribution, surface

area, porosity and surface activity, along with mineralogical structure and characteristics, influence the minerals' ability to adsorb unwanted particles.

The performance of bleaching earth in adsorbing colourant particles is primarily attributed to the aluminium ions present on the adsorbent's surface. Bentonite clay can be processed into activated bleaching earth but has a higher concentration of montmorillonite. Activation refers to the application of chemical or physical treatments to specific clay types to enhance their ability to absorb colouring matter and other impurities in oils and solutions (Babaki *et al.*, 2008; Diaz & De Souza Santos, 2001). These treatments or modifications can be categorised into three main groups as shown in Figure 3: (1) Physical modification, involving changes in chemical composition and crystalline structure through high-temperature or microwave treatment, (2) chemical modification, typically altering the structure and surface functional groups, and (3) pillaring treatment, a combination of chemical and physical processes that enhance the clay mineral structure's adsorption capacity or create spaces for the adsorption of specific ions (Hussin *et al.*, 2011).

Acid treatment stands as a widely employed chemical modification of bleaching earth (Komadel



Source: Husin *et al.* (2011).

Figure 3. Modification of bleaching earth.

*et al.*, 2006). In this process, mineral acids like hydrochloric acid (HCl) or sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) are utilised to activate the adsorbent. The acid treatment increases the adsorbent's surface area by dissolving or reacting with materials such as tar, calcium, and magnesium salts that coat its pores. This enhancement significantly improves the adsorbent's bleaching capacity (Tanjaya *et al.*, 2006). The presence of silanol (Si-OH) groups on the adsorbent's surface, in proportion to the amount of silica dioxide (SiO<sub>2</sub>) present, allows for the absorption of free fatty acids, organic materials and other polar chemicals like peroxides (Yang, 2003).

The activation process begins with the exchange of H<sup>+</sup> ions from the acid with cations from mineral salts (Ca<sup>2+</sup> and Mg<sup>2+</sup>) in the bentonite interlayer. Subsequently, Al<sup>3+</sup> ions and other metal ions, such as Fe<sup>3+</sup>, are dissolved from the lattice layers of bentonite. This dissolution imparts a negative charge to the bentonite, thereby enhancing its capacity to absorb acid, resulting in activated clay. Furthermore, the dissolution of ions during acid activation contributes to an increase in the clay's surface area (Hussin *et al.*, 2011).

Volcanic ash that undergoes natural transformation over the years can serve as a raw material for the formation of bleaching earth. These bleaching earths can be found in regions with volcanoes, such as in Europe, North and South America, the Middle East, and Asia, including Indonesia. The extensive utilisation of activated bleaching earth in the global market is estimated to reach around USD4.00 billion by the year 2032, with a projected Compound Annual Growth Rate (CAGR) of 5% from 2022 to 2032. In 2022, the estimated market value for activated bleaching earth is expected to be USD2.46 billion (Nikhil,

2022). The increasing demand for edible oils due to the world's expanding population is a primary driver of the demand for activated bleaching earth.

Additionally, the growing interest in biodiesel production has further fueled the demand for activated bleaching earth (Oils & Fats International [OFI], 2016). Moreover, developed countries are witnessing a rise in the adoption of healthier eating habits and low-fat oils, which is contributing to the demand for activated bleaching earth in North America and Europe (Nikhil, 2022).

### SBE By-product from Refinery RBD Palm Oil Plant

The refining process of CPO into RBD Palm oil typically involves three phases: Degumming, bleaching and deodorisation (Ahmed *et al.*, 2019; Ifa *et al.*, 2021; Nidzam *et al.*, 2022; Tan *et al.*, 2021). Throughout the process of refining at the plant, the bleaching earth becomes a by-product referred to as SBE. SBE is a solid oil waste generated during the refining of CPO and serves as an industrial residue resulting from the bleaching earth's utilisation in the production of edible oils.

The colour of the refined CPO serves as a crucial quality indicator and increasing the quantity of bleaching earth used can result in a lighter-coloured product. However, it is important to note that bleaching earth eventually becomes deactivated after its use in the purification process. This deactivation occurs as the surface of the bleaching earth becomes coated with impurities during the refining of CPO. These impurities encompass phosphatides, gums, metals, fatty acids and dyes present in CPO. *Figure 4* illustrates the production process of SBE.

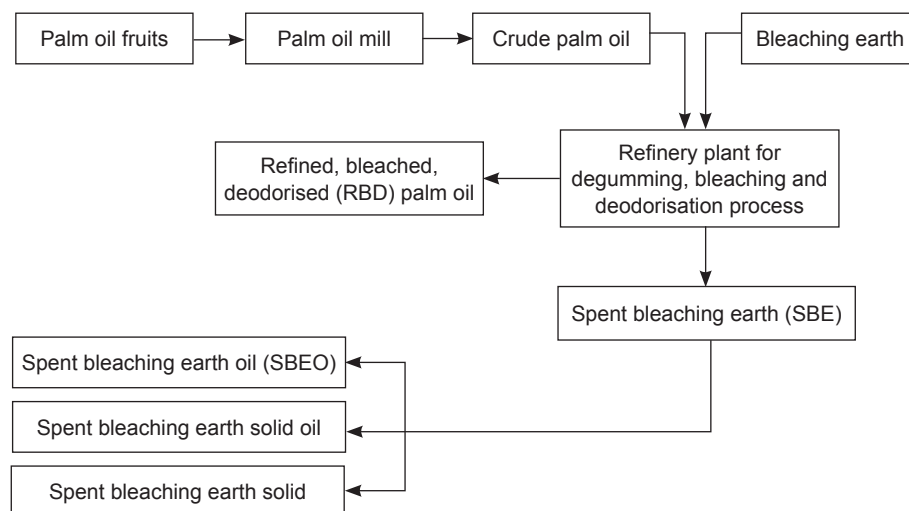


Figure 4. Production of spent bleaching earth (SBE).

The composition of material contained (by %) in SBE is shown in *Table 2*.

**TABLE 2. CHEMICAL COMPOSITION IN SPENT BLEACHING EARTH**

No.	Component	%
1	SiO <sub>2</sub>	83.05
2	Al <sub>2</sub> O <sub>3</sub>	3.93
3	Fe <sub>2</sub> O <sub>3</sub>	3.57
4	CaO	0.41

Source: Ashari *et al.* (2017).

In accordance with the Republic of Indonesia Law Number 101 of 2014, SBE was classified as hazardous waste under category number 2 (Indonesian Government Regulation, 2014). Consequently, mills were required to designate specific areas for the storage of this waste and ensure its proper disposal by entrusting it to authorised companies for recovery. However, in line with the Republic of Indonesia Law Number 22 of 2021, SBE has been reclassified as non-hazardous waste, thereby allowing private entities to engage in its utilisation and recovery (Indonesian Government Regulation, 2021).

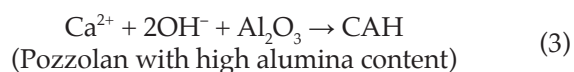
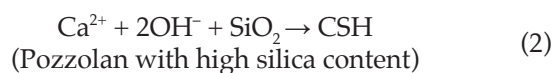
A portion of the SBE waste can be recovered and transformed into sustainable materials, including recovered oil (R-Oil), de-oiled bleaching earth (De-Obe), and EPP. Meanwhile, other waste is appropriately disposed of in landfills or other designated facilities, with waste management practices adhering to national regulations (Research Team PASPI, 2020). SBE comprises several significant components, such as silica oxide, alumina oxide, ferro oxide and oil residues. The oil residues constitute approximately 20%-30% of the waste, alongside solid components like ash. These constituents can be separated to yield two distinct products: The liquid phase, referred to as SBE oil or recovered oil and the solid phase known as SBE Solid-Oil or De-Obe, which contains an oil content of less than 3%. The extraction process responsible for this separation is known as solvent extraction (SE) technology, and it has been implemented for the extraction of SBE (Research Team PASPI, 2020).

The liquid phase recovered oil from SBE has various applications including its use as feedstock for biodiesel and bio-lubricants (Abdulbari *et al.*, 2011; Aladetuyi *et al.*, 2014; Kheang *et al.*, 2007; Suryani *et al.*, 2017; Widyawati & Ufidian, 2017). On the other hand, the solid phase, De-Obe which contains a minimal amount of CPO, can be utilised as a fuel in boilers to generate steam. The produced steam can be employed within the refinery, including in the solvent extraction process or other processes to heat the CPO. After combustion, De-Obe is transformed into either spent bleaching earth solid or EPP (Abdelbasir *et al.*, 2023).

The chemical composition and physical properties of EPP are contingent on the specific bleaching earth utilised. EPP's chemical composition is as follows: Silica dioxide 47.60%, aluminium oxide 11.60%, iron oxide 9.80%, calcium oxide 12.55%, magnesium oxide 6.20% and loss on ignition (LOI) 5.78%. In terms of particle size distribution, EPP exhibits the following characteristics: Particle size  $d=10$  ( $\mu\text{m}$ ) 7.04%, mean particle size  $d=50$  ( $\mu\text{m}$ ) 29.30%, particle size  $d=90$  ( $\mu\text{m}$ ) 80.42% and a specific gravity of 1.93 (Raihana *et al.*, 2019).

### Type of Pozzolan

Pozzolan is a substance containing silica or silica-alumina and alumina oxide. Unlike cement, it does not possess inherent binding properties. However, when it takes the form of fine granules and reacts with water, these compounds undergo a reaction with calcium hydroxide at room temperature. This reaction leads to the creation of hydraulic calcium hydrates characterised by relatively low solubility rates (Becerra-Duitama & Rojas-Avellaneda, 2022; Sanchez De Rojas & Frias, 2013). The definition of pozzolan relies not on the material's source but on its capacity to react with lime and water. When pozzolan encounters lime in the presence of water, it releases OH<sup>-</sup> ions, resulting in a pH increase (typically around 12.4). This pH rise triggers pozzolanic reactions, wherein silicon and aluminium combine with available calcium, culminating in the formation of cementitious compounds known as calcium aluminate hydrates (CAH) and calcium silicate hydrates (CSH). These reactions can be summarised as follows (Pourakbar & Huat, 2016).



The presence of sulphates (SO<sub>4</sub><sup>2-</sup>) in pozzolans has a detrimental effect on pozzolanic reactions because it results in the formation of a highly hydrated mineral known as ettringite [Ca<sub>6</sub>Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>(OH)<sub>12</sub>·26H<sub>2</sub>O]. The formation of ettringite is contingent upon the availability of soluble aluminium, calcium and sulphates, elevated pH levels, and the presence of water. High temperatures can expedite the formation

of ettringite and its occurrence can be rapid depending on environmental conditions. Ettringite is characterised by its expansive nature, indicated by the presence of 26 water molecules and this expansion has the potential to harm cementitious materials produced through pozzolanic reactions (Seco *et al.*, 2012).

Furthermore, pozzolanic materials contain significant quantities of silicon, iron and aluminium oxides. To qualify as a pozzolan, the combined weight percentage of these three oxides must be at least 70%. These chemical compounds play a crucial role in the formation of a cementitious gel known as C-S-H. However, the extent of paste formation within the mixture is influenced by several factors, including the specific surface area of the pozzolan, its intrinsic properties, the chemical compounds present, the pozzolan's extraction method and the content of reactive silica.

### Physical and Chemical Properties Pozzolan

The physical and chemical properties of pozzolan can be described according to the ASTM Standard C618-12a (2019). The chemical properties of pozzolan in classes N, F and C depend on the composition  $Al_2O_3$ ,  $SiO_2$ ,  $SO_3$ ,  $Fe_2O_3$ , and moisture content. On the other hand, the physical properties are determined by factors such as fineness, strength activity index, water requirement and soundness. The minimum composition of  $SiO_2$  combined with  $Fe_2O_3$  and  $Al_2O_3$  for Class N is 70%, for Class F is 70%, and for Class C is 50%.

### The Classification of Pozzolan

According to ASTM C618-92a (1994), the quality standards for pozzolan are classified into three classes based on their physical properties and chemical composition. The quality of pozzolan is considered good if the levels of  $Fe_2O_3 + SiO_2 + Al_2O_3$  are high and if it exhibits high reactivity with lime. The three classes of pozzolan are as follows: Class N, Class C and Class F.

Natural pozzolan can vary in terms of quality, shape, and colour depending on the specific deposit. For example, the quality of pozzolan in one area like Kalibagor, may differ from that in other areas like Wingi or Blitar. Due to these variations, it is important to standardise the quality of pozzolan using ASTM standards to ensure consistent and controlled quality.

### Ordinary Portland Cement Specification

Cement, in general, is a material known for its ability to bind different substances through various reactions, often facilitated by the

presence of water (Bahhou *et al.*, 2021; Paul *et al.*, 2018). Cement is a crucial industrial commodity produced commercially in more than 120 countries, primarily used in the construction of buildings, roads, bridges and other structures. Cement is indispensable in the production of concrete, its utilisation surpassing more than twice that of other building materials involved in the concrete-making process. Ordinary Portland Cement (OPC) stands as the most extensively utilised type of cement, well-suited for a wide range of general concrete construction applications.

The performance of concrete made with OPC strongly hinges on the characteristics of the cementitious binder and the environmental conditions to which it is exposed. Cement production primarily involves grinding raw materials, blending them in specific proportions, and then subjecting them to high-temperature sintering in a large rotating kiln, resulting in small gray clinker pellets. After cooling, these clinkers are mixed with a minor quantity of gypsum to regulate the setting time and are further finely ground in ball mills before packaging. The composition of raw materials utilised in cement production is meticulously controlled within defined parameters. *Table 3* (Ali *et al.*, 2008) illustrates the elements in Portland Cement, while *Table 4* (Vidican *et al.*, 2008) presents the bogue compounds formed because of chemical reactions during the burning and fusion of raw materials. *Table 5* (Sutar *et al.*, 2021) provides detailed information about the composition of these bogue compounds.

TABLE 3. CHEMICAL CONSTITUTIONS OF OPC

Components	Percentage (%)
Lime (CaO)	60.0 to 67.0
Silica ( $SiO_2$ )	17.0 to 25.0
Alumina ( $Al_2O_3$ )	3.0 to 8.0
Iron oxide ( $Fe_2O_3$ )	0.5 to 6.0
Magnesium oxide (MgO)	0.1 to 4.0
Sulphur trioxide ( $SO_3$ )	1.0 to 3.0
Soda and/ or Potash ( $Na_2O+K_2O$ )	0.5 to 1.3

Source: Ali *et al.* (2008).

TABLE 4. BOGUE COMPOUNDS

Compound abbreviated designation	Abbreviated designation
Tricalcium silicate ( $3CaO.SiO_2$ )	C3S
Dicalcium silicate ( $2CaO.SiO_2$ )	C2S
Triacalcium aluminate ( $3CaO.Al_2O_3$ )	C3A
Tetra calcium alumina ferrite ( $4CaO.Al_2O_3.Fe_2O_3$ )	C4AF

Source: Vidican *et al.* (2008).

TABLE 5. COMPOSITION AND COMPOUND OF PORTLAND CEMENT

Portland cement	Normal	Rapid hardening	Low heat
(a) Composition (%)			
Lime (CaO)	63.1	64.5	60.0
Silica (SiO <sub>2</sub> )	20.6	20.7	22.5
Alumina (Al <sub>2</sub> O <sub>3</sub> )	6.3	5.2	5.2
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	3.6	2.9	4.6
(b) Compound (%)			
C3S	40.0	25.0	25.0
C2S	30.0	21.0	35.0
C3A	11.0	9.0	6.0

Source: Sutar *et al.* (2021).

The manufacturing of Portland Cement involves four distinct phases. (1) Raw materials are ground and crushed, (2) blending the materials in the correct proportions, (3) subjecting the created mixture to high temperatures in a kiln, and (4) pulverising the resulting product, referred to as clinker, along with around 5% of gypsum (to regulate the setting time of the cement). The three manufacturing processes are known as the wet, dry, and semidry processes. These terms characterise how raw materials are readied and introduced into the kiln. During the wet process, the raw materials are milled in a wet state and subsequently conveyed as a slurry. In the dry process, before being introduced into the kiln, the raw materials will be pulverised. In the semidry process, before being fed into the kiln, the raw materials are initially ground dry and then moistened to create modules (Fasi, 2018; Sutar *et al.*, 2021).

### Types of Portland Cement

The differentiation of OPC cement is based on the different codes in different countries.

### Bureau of Indian Standards

Three distinct classes of OPC cements have been classified by the Bureau of Indian Standards (BIS) (2004; 2013; 2015). These grades are as follows: OPC 33 Grade, OPC 43 Grade and OPC 53 Grade cements in Table 6.

The minimum compressive strength that the cement must achieve is indicated by the grade number. For example, the minimum compressive strength of 53 Grade OPC that must be achieved in the 28 days must not be less than 53 MPa, which is equivalent to 530 kg/cm<sup>2</sup>. At this point, it is important to point out that the chemical composition of OPC 33, 43 and 53 grades is identical. The only difference lies in the fact that the higher-grade cement undergoes a more thorough grinding process during the final stage, resulting in a much finer consistency. This results in a product that is far more robust and long-lasting due to its superior strength and durability (Sutar *et al.*, 2021).

### OPC 33-Grade Cement

The compressive strength of OPC 33-grade cement is 33 N/mm<sup>2</sup> referred to Indian standard IS 269:2015, after 28 days. However, this grade of cement has become obsolete in recent years and is no longer in use. Furthermore, cement with a grade of 33 is not suitable for use in the production of concrete with a grade of M20 or higher. It is typically employed for general construction purposes under normal environmental conditions. Nevertheless, the utilisation of OPC 33 has declined due to its lower compressive strength and the ready availability of higher-grade cement.

TABLE 6. OPC COMPRESSIVE STRENGTH

Period	Compressive strength		
	OPC 33-grade <sup>1</sup>	OPC 43-grade <sup>2</sup>	OPC 53-grade <sup>3</sup>
72 +/- 1 hr	Not less than 16 N/mm <sup>2</sup>	Not less than 23 N/mm <sup>2</sup>	Not less than 27 N/mm <sup>2</sup>
168 +/- 2 hr	Not less than 22 N/mm <sup>2</sup>	Not less than 33 N/mm <sup>2</sup>	Not less than 37 N/mm <sup>2</sup>
672 +/- 4 hr	Not less than 33 N/mm <sup>2</sup>	Not less than 43 N/mm <sup>2</sup>	Not less than 53 N/mm <sup>2</sup>

Note: <sup>1</sup> IS Code - IS 269: 1989 for OPC, 33 Grade; <sup>2</sup> IS Code - IS 8112: 1989 for 43 Grade OPC; <sup>3</sup> IS Code - IS 12269: 1987 for Specification for 53-grade OPC.

Source: Sutar *et al.* (2021).

### OPC 43-Grade Cement

According to the Indian standards outlined in IS 8112:2013, the compressive strength of cement is 43 N/mm<sup>2</sup>. This cement is familiar with OPC 43-grade cement, which is well-known. This grade of cement produce concrete with grades as high as M30. Additionally, it finds applications in various areas, including brickwork mortar, precast products like tiles and cement pipes and even plain cement concrete, commonly referred to as PCC.

### OPC 53-Grade Cement

This cement is of superior quality and readily available for purchase in the market. Cement with a compressive strength of 53 N/mm<sup>2</sup> is referred to as OPC 53-grade cement. The cement's curing time is faster in comparison to the OPC 33 and 43-grade cement. Using OPC 53-grade cement makes it easily attainable to achieve any grade higher than M25. This cement variant is specifically employed in the construction of precast walls, concrete roadways, bridges, dams and reinforced concrete structures.

### American Standard OPC ASTM C150-07

Portland cement is classified into eight types based on specific specifications, these types include Type I, IA, II, IIA, III, IIIA, IV and V. The cement outlined in this specification shall exclusively comprise the following constituents: Limestone, an air-entraining addition for air-entraining Portland cement, Portland cement clinker, processing additions and water or calcium sulfate or a combination of both (Fasi, 2018).

### European Standard OPC EN 197

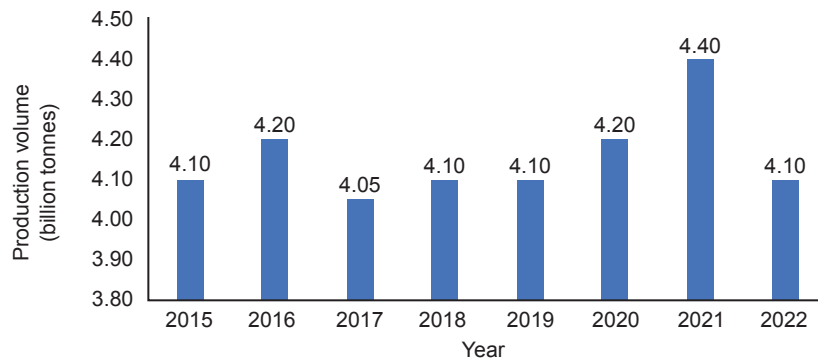
The OPC standard for Europe, as per EN 197, has five types including CEM I, CEM II, CEM III, CEM IV, and CEM V based on composition, specifications and conformity criteria for common cement (Fasi, 2018).

In 2022, the global cement output reached an approximate volume of 4.10 billion tonnes (Figure 5). In 1995, the worldwide production of cement was just 1.39 billion tonnes, demonstrating the significant expansion of the building sector since that time (Statista Research Department, 2023).

### The Strength Analysis of the Use of Processed Spent Bleaching Earth (PSBE) in Concrete

Various studies have explored the potential utilisation of EPP as a sustainable alternative to cement in different construction applications. Kusaimi *et al.* (2020) conducted a study concentrated on integrating EPP as a cement substitute in pavement blocks. The research aimed to evaluate the performance of pavement blocks formulated with EPP, considering properties such as water absorption and compressive strength. Two variations of paving blocks were formulated: Set A, where EPP partially replaced cement in pavement formulation (ranging from 20% to 90% substitution) and Set B, which integrated both EPP and FA as some cement replacements. The research indicated that adding FA resulted in pavement blocks achieving a maximum compressive strength of 36 MPa when EPP was added at a rate of 15%-20%. It was concluded that the maximum EPP addition to the pavement formulation should not exceed 20%.

Yunus *et al.* (2019) investigated the compressive strength of EPP concrete under chloride and sulphate exposure conditions. The study found that concrete containing EPP exhibited higher compressive strength compared to concrete without EPP when exposed to water for 28 days. This suggested the occurrence of chemical interactions involving the silica in EPP and the calcium hydroxide led to pozzolanic reactions released during OPC hydration, contributing to concrete strength development. However, exposure to a 3.5% sodium chloride solution led to a decrease in compressive strength, highlighting the need to consider specific exposure conditions for optimal EPP concrete performance.



Source: Statista Research Department (2023).

Figure 5. Global cement production volume from 2015 to 2022.

Raihana *et al.* (2019) focused on investigating EPP properties and their potential as a cement substitute in mortar and concrete. The study concluded that EPP exhibited pozzolanic properties due to its high SiO<sub>2</sub> content, making it suitable as a partial cement replacement. The research highlighted that up to 20% EPP may serve as a substitute for cement in mortar and concrete, contributing to reduced environmental impact associated with cement production.

Kho (2021) explored partial cement replacement by EPP and superplasticisers in concrete. The study found that the addition of EPP led to changes in workability, making the concrete easier to compact. However, the use of superplasticisers improved workability and strength, achieving comparable compressive strengths to 100% OPC concrete.

Jones and McCarthy (2005) investigated foamed concrete using EPP as a cement substitute. The research attained a compressive strength of 28 MPa at a 30% EPP replacement of cement in foamed concrete, suggesting its viability for structural applications.

Rokiah *et al.* (2019) examined the influence of PSBE on foamed concrete's compressive strength and observed that replacing 30% of the cement with PSBE enhanced compressive strength and other properties of the foamed concrete mixture.

Othman *et al.* (2021) explored the use of PSBE as a partial cement substitute in foamed concrete, achieving the desired density, stability, workability, and significantly increased compressive strength.

Ahmat *et al.* (2023) in geopolymer concrete, substituting FA with EPP within the range of 10% to 30% yields compressive strengths above 28 but does not reach 40 MPa.

Those studies collectively demonstrate the potential of EPP in enhancing concrete performance while reducing reliance on traditional cement, contributing to sustainable construction practices. For a detailed comparison of compressive strength from various experiments, refer to *Table 7*.

**Fire Resistance Properties in Concrete with Additional Material**

Concrete has inherent fire-resistant properties, which make it suitable for applications where fire protection is important (Korytchenko *et al.*, 2021). Low thermal conductivity is a factor in the fire resistance of concrete, along with a high thermal inertia factor. The low thermal conductivity of concrete slows down the transfer of heat during a fire, preventing the rapid spread of flames and limiting damage to the structure. This property

**TABLE 7. COMPARISON OF COMPRESSIVE STRENGTH OPC WITH EPP IN MIXTURE CONCRETE**

No.	Material/ Condition used	Outcome	References
1	EPP as some cement substitute in pavement blocks	The highest compressive strength of the pavement block is observed when FA and EPP are added, reaching a compressive strength of 36 MPa, with EPP added at levels between 15% to 20%. It's important to note that the limitation for adding EPP is not to exceed 20%.	Kusaimi <i>et al.</i> (2020)
2	Concrete mix cement with EPP	The compressive strength of E20 (Concrete mix with 20% EPP) was 34.2 MPa after 28 days of curing, which was higher than E0 (100% OPC) 30.13 MPa, E10 (Concrete mix with 10% EPP) 32.10 MPa and E30 (Concrete mix with 30% EPP) 26.72 MPa.	Yunus <i>et al.</i> (2019)
3	Mortar mix cement with EPP	In comparison to a control specimen consisting of 100% OPC in mortar, a mortar incorporating a 20% replacement of EPP as a substitute for cement demonstrates varying compressive strengths. After 7 days of curing, the strengths are recorded as 13.50 MPa for OPC and 15.26 MPa for the 20% EPP substitution. Subsequently, after 28 days of curing, there is a further increase in compressive strength, with values reaching 25.53 MPa for OPC and 26.61 MPa for the 20% EPP substitution.  Additionally, it's noteworthy that the strength activity index of EPP for both the 7 day and 28 day periods is reported to be above 101%.	Raihana <i>et al.</i> (2019)
4	Combining fine aggregate FA and EPP as cement replacement in foamed concrete	Compressive strength 28 MPa is achieved by combining fine aggregate FA and EPP as a cement replacement rate of 30% in foamed concrete with a density of 1,600 kg/m <sup>3</sup> .	Jones and McCarthy (2005)
5	Utilising PSBE in the production of foamed concrete	Utilising 30% and 40% PSBE in the production of foamed concrete, the highest flexural strength 6 MPa is obtained with a curing time of 28 days. In comparison, the control foamed concrete (100% OPC) achieved flexural strength of 2 MPa.	Rokiah <i>et al.</i> (2019)
6	EPP as a substitute for fly ash in geopolymer concrete	EPP as a substitute for fly ash in geopolymer concrete found that using 10%-30% EPP as a replacement for fly ash resulted in compressive strengths ranging from 28-39 MPa.	Ahmat <i>et al.</i> (2023)

helps to compartmentalise the building and prevent the fire from spreading to other areas, providing additional time for evacuation and firefighting efforts (Smedberg *et al.*, 2023).

Concrete walls and partitions act as effective barriers in containing fire within a specific area, helping to control its spread and minimising property damage. This is particularly important in commercial and industrial settings where warehouses and storage buildings contain valuable goods and materials. Furthermore, the fire-resistant nature of concrete can result in reduced fire insurance rates for buildings constructed with concrete. Insurance companies recognise the fire-resistant qualities of concrete structures and often offer lower premiums as a result.

It is important to note that while concrete provides fire resistance, it is not entirely immune to fire. High temperatures and prolonged exposure to fire can cause concrete to undergo thermal spalling, which is the breaking off of surface layers due to the rapid expansion of moisture trapped within the concrete. However, concrete's ability to withstand fire and its contribution to overall fire safety make it a preferred construction material in many applications (Templeton *et al.*, 2023).

When concrete made of OPC is subjected to heat, the water within its pores and capillaries evaporates as the temperature rises. The temperature reaches 100°C, and both water and hydrated calcium silicate in the cement paste begin to evaporate, resulting in a reduction in strength. The increased vapour pressure within the concrete pores can cause explosive spalling, where certain portions detach from the surface, typically occurring at temperatures exceeding 300°C. Exposed to temperatures surpassing 600°C, a crack manifested on the surface. Subsequent temperature increments to 720°C and 950°C resulted in the generation of additional cracks, leads to significant weakening and brittleness of the concrete, resulting in a loss of its structural integrity (Li *et al.*, 2022; Sulistyawati, 2005).

Lubloy *et al.* (2017) examined the fire resistance of concrete, involving different types of specimens such as cement paste and concrete. It compared the performance of blended and OPC, considering various curing durations. The findings demonstrated that the concrete specimens prepared with pozzolans and fly ash-containing Portland-composite cement exhibited higher or at least equal relative residual compressive strength compared to the concrete specimens prepared with OPC.

Umasabor and Okovido (2018) conducted research that centred on assessing the fire-resistant properties of concrete samples incorporating rice husk ash (RHA). In the experimental method utilised in the study, concrete specimens were prepared by incorporating varying percentages of RHA (5%, 10% and 15% by weight) as some

substitute for OPC. Following the curing process, the samples underwent testing at various intervals, spanning from seven to 200 days. Subsequently, these specimens were exposed to temperatures ranging between 100°C-700°C for 2 hr in a muffle electric furnace. The study's findings indicate that OPC can be successfully substituted with RHA pozzolans, with a weight replacement of up to 15%, in grade 20 binary blended cement. This replacement, when subjected to curing for up to 200 days, does not result in a reduction of its compressive strength.

Farzadnia *et al.* (2013), conducted research on mortar specimens with the replacement of cement by 1% to 3% nano-alumina. These specimens were then exposed to temperatures ranging from 100°C to 1,000°C. The research results concluded that by adding 1% nano-alumina at room temperature, the compressive strength of the mortar can increase up to 16%. After exposure to high temperatures, a decrease in strength occurred in all test samples. However, the residual compressive strength remained higher than the original levels when 1% nano-alumina was added, even at temperatures up to 800°C.

Bendary *et al.* (2023) study evaluated the impact of firing temperature on the properties of pozzolanic cement. Specimens were prepared by OPC with different mass ratios of imported granulated blast furnace slag (IGBFS): A1 (30% OPC, 70% slag), A2 (40% OPC, 60% slag), A3 (50% OPC, 50% slag) and A4 (60% OPC, 40% slag). The compressive strength initially rises with temperature up to 250°C, but beyond this point and up to 800°C, it starts to decrease. At 800°C, the highest compressive strength is observed in sample A1, A2, A3 and A4, respectively.

## CONCLUSION

In conclusion, these findings support EPP as viable substitute for OPC in blended concrete applications. Most of EPP research focused on compressive strength analysis but less on heat transfer analysis. Therefore, there is a need to explore the heat transfer on EPP. The suitability of different pozzolans for cement substitution may vary due to their unique characteristics. Determining the optimal percentage of cement replacement depends on several factors, including the specific type of pozzolan used, the curing duration, and the composition of aggregates in the concrete mixture. These findings highlight the potential of EPP and similar pozzolanic materials as sustainable alternatives to reduce the reliance on OPC in concrete production. However, it is essential to consider various factors when determining the most suitable pozzolan and the percentage of substitution for a given concrete application.

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