Microstructure And Durability Performance Of Concrete Containing Empty Palm Oil Fruit Bunch Ash As Partial Replacement Of Ordinary Portland Cement

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Abstract

Sustainable construction is a rapidly increasing research area. Investigators of all backgrounds are using industrial and agro wastes to replace Portland cement in concrete to reduce greenhouse emissions and the corresponding decline in general health. Many types of wastes have been used as cement replacements in concrete including: fly ash, slag and rice husk ash in addition to others. This study investigates the possibility of producing a sustainable approach to construction through the partial replacement of concrete using biofillers. This will be achieved by studying the physical and mechanical properties of two widely available biological wastes in Malaysia; eggshell and palm oil fuel ash (POFA). The mechanical properties tests that were studied and compared are the compression, tensile and flexural tests.

1. Introduction

Concrete has played a crucial role in developing the infrastructure of all nations. Traditionally concreteis produced using the components: cement, sand, gravel and water. Nowadays, however, more emphasisis being placed on sustainable construction. It is stated that producing 1 ton of Ordinary Portland cementreleases an equal amount of carbon dioxide (CO_2) into the atmosphere [1]. Therefore, taking intoaccount this huge amount of CO_2 emanating from cement manufacturing with all their adverseenvironmental and health effects, concrete had to have its share of sustainable construction practices. Based on that there has been an increasing trend of using waste materials in construction to reduce theamount of cement used and hence the environmental pollution with all its adverse health effects.Researchers are using different types of waste materials more than any time before to improve thelivelihood of societies and to manage the waste materials produced by different industries. This studyis an attempt to investigate the applicability of using two locally produced agro wastes in Malaysia;eggshells and palm oil fuel ash (POFA).

Eggshells are a waste product produced by the food industry in restaurants, poultry farms and bakery shops. Eggshells consists of three layers which are the outer eggshell, outer shell membrane and inner shell membrane. The outer eggshell is made up of calcium carbonate $CaCO_3$ which is covered with tinypores, [2]. The shell also consists of a thin outermost coating called the cuticle and it is the thickest partof the eggshell. While the outer and inner shell membranes are made up of keratin. The eggshell mainlyconsists of calcium, magnesium carbonate (lime) and protein. Chicken eggshell has been listed worldwide as one of the worst environmental problems [3]. According to Raji and Samuel [4], the disposal of eggshell has the potential to cause environmental pollution, due to its availability and chemical composition, hence proper management and treatment is required. Figure 1 shows a sample of eggshell powder (ESP).

Figure 1. A sample of eggshell powder.

Palm oil fuel ash (POFA) is another waste that needs recycling in Malaysia. South East Asia, including Malaysia, is said to be one of the largest regions of producers of palm oil with millions of tons being generated annually [5]. POFA is the ash that is produced by burning the husk fibre and shell of palm oil through a generation plant boiler that generates energy to be utilized in palm oil mill. Traditionally,POFA is disposed of in landfills. This method of disposal, however, have been is generating a lot of criticism because of the various health and environmental hazards generated [6]. To counter that several researchers have attempted to re-use POFA sustainably, and it was found that POFA can be used as an alternative product in the construction industry. Specifically, as a supplementary cementitious material in concrete [6-9].

POFA is greyish and almost dark in colour as shown in Figure 2. According to Olowe and Adebayo [10], POFA is a highly pozzolanic material that can be used for partial cement replacement and has the potential to increase the compressive strength and durability of concrete.

Figure 2. Palm oil fuel ash.

One common material that can be used as a sustainable product in concrete applications is eggshell. Eggshell waste is a waste from the food industry. They are mainly produced from the chick hatcheries,

bakeries and food restaurants. When the eggshell ash is being used in concrete, the construction materials will be more economical hence reducing the environmental pollution.
This study investigates the possibility of producing a sustainable approach to construction through the partial replacement of concrete using hybrid biofillers. This will be achieved by studying the physical and mechanical properties of two widely available biological wastes in Malaysia; eggshell and palm oilfuel ash (POFA). The mechanical properties tests that will be studied are the compression, tensile and flexural tests.

2. Previous Research

Throughout the years researchers have been using a wide array of supplementary cementitious materialsand waste products with concrete. The aim of which is to reduce greenhouse emissions through the reduction of cement used, and to find an alternative disoposal method for these wastes. These supplementary cenemtitious materials include: fly ash, blast-furnace slag, natural pozzolans andbiomass ash, in addition to others.

Also, agricultural wastes have been used as pozzolanic materials in concrete such as POFA and silica from rice husk and rice husk ash [11]. Using these materials in sustainable construction applications will help in reducing landfill cost, save energy resources, and protect the environment from any possiblepollution effects. Sooraj [12] states that, in comparison to Ordinary Portland cement, these materials improve the microstructure and mechanical properties of concrete. In this research two such agro wastesare being studied as cement replacements in concrete; eggshell and POFA. These two wastes constitutea large portion of the wastes being produced in locally in Malaysia.

Eggshell powder

Several researchers attempted to use waste materials to improve the mechanical properties of concrete and to reduce waste disposal problems. Major waste materials that have been used, so far, are fly ash, silica fume, pozzocrete, quartz sand, egg shell powder [13][14] in addition to others. Eggshell disposalis said to be contributing to environmental pollution, causing undesirable odours, which cause irritationand affect the wellbeing of humans.

The main ingredient in eggshells is calcium carbonate ($CaCO_3$). The shell itself is said to be made up of 95% of $CaCO_3$ while the remaining parts are made up of magnesium, aluminium, phosphorous, sodium, potassium, zinc, iron, copper, ironic acid and silica acid. Having a cellulosic structure with amino acids, eggshells can act as a good bio-sorbent [2]. According to Nadu [15], using eggshell will assist in reducing the alkali-silica and sulphate expansions. Eggshells have been shown to possess excellent durability and a washable finish. Eggshell can resist mould and mildew on paint film. Using eggshells has economic benefits and has the potential to meet strict performance as well as aesthetic requirements [15].

Table 1. Chemical properties of cement and ESP [16].

Composition	**Cement**	**ESP**
CaO	63.8%	47.49%
SiO_2	21.4%	0.11%
Al_2O_3	5.1%	-
Fe_2O_3	2.6%	Traces
MgO	0.36%	-
SO_3	3.38%	0.38%
K_2O	1.88%	-
Na_2O	0.14%	0.14%
Specific gravity	3.12	2.14

In this research, eggshells have been collected from a bakery shop and a local restaurant in Sibu, Sarawak. They were oven dried for half an hour in order to completely remove the moisture contained in the eggshells. Next, the eggshells were grinded using a blender before being sieved, to transform them into powder form. The chemical properties of cement and Eggshell powder (ESP) are shown in Table 1 [16].

Mechanical Properties

Compressive Strength

Gajera [13] showed that the optimum replacement ratio for eggshell powder is 10%. At this ratio, both replacement and control samples reached the same strength. He concluded that when replacement ratiowas increased up to 20%, problems of bleeding, micro cracks and segregation might occur. A few yearsearlier, Praveen et al. [17] had reached a similar conclusion with the optimum eggshell-cement replacement ratio of 15%.

Likewise, Raji and Samuel [4] studied the compressive strength of eggshell concrete. It was found thatwith up to 7.5% of eggshell replacement at 7 and 28 days of curing, strength reached 38 MPa and 40.9 MPa, respectively. While control concrete mixtures under similar conditions reached strengths of 42 MPa and 49.5 MPa, respectively. The gap between both sample strengths further decreased At 56 daysof curing with eggshell and control concrete samples having 48.4 MPa and 51.6 MPa of strength, respectively. In a similar fashion, Nadu [15] showed that, in order to meet strength requirements, the optimum percentage of cement replacement with eggshell powder was 20%. A corresponding reduction in the weight of concrete cubes from 2 kg to 2.8 kg, was noticed. However, increasing the replacementratio of eggshell powder above the optimum caused a reduction in the compressive strength of concrete. Likewise, Yerramala [18] showed that the optimum replacement ratio of eggshell was 15%. At this ratio replacement samples achieved 14.4 MPa and 24 MPa at 7 day and 28 day of curing, respectively, versus 11.1 MPa and 22.3 MPa for control concrete samples. When the eggshell percentage was increased to 30%, compressive strength declined to 10.7 MPa and 18.9 MPa at 7 day and 28 day curing,respectively. When using eggshell replacement ratios of 5% and 10%, Jayasankar et al. [19] found thatconcrete had achieved the minimum required strengths of 35 and 32.2 MPa, respectively.

Tensile Strength

Gajera [13] showed that increasing the percentage of eggshell powder decreased the tensile strength, elongation and resilience of concrete mixtures. The tensile strength of these concrete mixtures decreasedfrom 22.4 MPa to 9.7 MPa when the eggshell powder was increased from 5% to 25%. A Similar conclusion had been reached earlier by Praveen et al. [17] and Nadu [15]. Meanwhile, Yerramala [18]showed that eggshell powder concrete with 15% replacement ratio reached the same strength as control concrete at 28 days of curing. However, increasing eggshell powder content to 30%, caused the split tensile strength of concrete to decrease.

Flexural Strength

Praveen et al. [17] showed that flexural strength of eggshell concrete increased when eggshell powder is added up to 15%. While Nadu [15] showed that flexural strength decreased with increasing eggshellcontent. In this study, flexural strength at 28 days of curing decreased from 2.86 MPa to 0.99 MPa when eggshell content was increased from 0% to 50%.

Palm Oil Fuel Ash (POFA)

Another potential recycling material from the palm oil industry is palm oil fuel ash. Palm oil is extractedfrom the fruit and copra of the palm oil tree. After the extraction process, the waste products such as palm oil fibers, shells and empty fruit bunches are burnt as biomass fuel to boil water. This resulting heat generates steam for electricity and the extraction process in palm oil mills. According to Sooraj [12], the result of the extraction process is palm oil fuel ash (POFA), which is 5% by weight, of the solid waste product.

Pozzolanic Activity

According to Al-Mulali et al. [20], the oil palm ash has high organic content, higher alkali content and is coarser than fly ash. As the particle size of oil palm ash becomes larger, its pozzolanic potential becomes smaller. It was shown that concrete, cured for one year, with 10% replacement of oil palm ash, sieved through a 150µm sieve, showed 1% reduction in compressive strength compared to control cubes[21].

Similarly, Tangchirapat et al. [22] showed that oil palm ash must be ground to a finer particle sized material to achieve better results. And Rukzon and Chindaprasirt [23] found that mortars incorporating fine oil palm ash as partial cement replacement with a median particle size of 7 µm showed higher compressive strength than control mortar specimens due to the filler effect and higher reactivity of fine oil palm ash. On the other hand, Hussin and Ismail [24] showed that ground POFA with a fineness of 10 µm can be used to produce high strength durable concrete, with a strength higher than that of concrete using POFA with a fineness of 45µm. The chemical analysis and physical properties of POFA and OPCare summarized in Table 2 [25].

Table 2. Physical properties and chemical analysis of OPC and POFA [25].

Tests	**OPC**	**POFA**
Physical Properties:		
Fineness – Specific Surface area (m^2/kg)	314	519
Soundness – LeChatelier method (m m)	1	1
Specific gravity	3.28	2.22
Chemical Analysis (%)		
Silicon Dioxide (SiO_2)	20.2	43.6
Aluminium Oxide (Al_2O_3)	5.7	11.4
Ferric Oxide (Fe_2O_3)	3.0	4.7
Calcium Oxide (CaO)	62.5	8.4
Magnesium Oxide (MgO)	2.6	4.8
Sulphur Trioxide (SO_3)	1.8	2.8
Sodium Oxide (Na_2O)	0.16	0.39
Potassium Oxide (K_2O)	0.87	3.5
Loss on Ignition (LOI)	2.7	18.0
Pozzolanic Activity Index with OPC	-	112

Mechanical Properties

Compressive Strength

Several researchers have conducted experiments on the use of agro waste ashes as replacement materials in concrete. For example, Bamaga et al. [26], showed that the compressive strength of OPC concrete containing 20% POFA at 28 and 90 days of curing could reach 48.7 and 53.02 MPa in comparison with 48.03 and 49.05 MPa for OPC concrete. It was postulated that this was due to high SiO_2 content of POFA that reacted with calcium hydroxide at later ages to produce impermeable concrete by producing

addition calcium silicate hydrate. It was shown that ground POFA could be used as cement replacement material to replace 20% of Portland cement [26][27].
Karim et al. [28] found that the optimum POFA replacement ratio for concrete was 20%, as the strength would decline beyond this value. While Ranjbar et al. [29] found that specimens containing 15% and 20% of POFA replacement ratio gained lower compressive strength in the early days of curing compared to the conventional control samples. Also, it was found that concrete replaced with ground POFA had relatively comparable or higher strength than plane concrete at a curing age of 28 days or more.
Deepak et al. [5] have found that the strength of concrete could be improved by using up to 25% of POFA to replace the Portland cement. Also, the compressive strength of POFA showed optimum strength when the cement was replaced with 15% POFA, which gave a higher compressive strength compared to OPC. While Olutoge et al. [11] discovered that the Palm Kernel Shell Ash (PKSA) Concrete at 28 days reached a strength of 22.80 MPa, which meets the minimum required strength of concrete at 28days.

Sooraj [12] discovered that with 10% of POFA added, the compressive-strength development at 7 dayswas greater than those of control samples. While at 28 days the compressive strength development wasclose to the control samples. The compressive strengths (in MPa) for concrete cubes with 0, 10, 20, 30 and 40% POFA replacement ratios of cement were: 36.89, 35.6, 32.7, 28.44 and 23.48, respectively. Subsequent to this, Olowe and Adebayo [10] showed that the compressive strength (in MPa) of concretewith 25% and 50% of PKSA replacement ratio at 7 days was 31.42 and 19.08, respectively. While compressive strength of control concrete samples reached 35.97 MPa.

Tensile Strength

Sooraj [12] showed that the tensile splitting strength measured at 28 days increased with the increase in POFA replacement ratio from 0% to 10%. When 20% of POFA was added, the tensile strength development was similar to control samples. Increasing the POFA replacement ratio to 30% caused a reduction in the tensile strength of concrete samples [12]. Olowe and Adebayo [10] showed that the tensile strength of control concrete at 56 days reached 4.03 MPa while concrete with 25% and 50% Palm Kernel Ash replacement ratios reached a split tensile strength (in MPa) of 5.31 and 4.39, respectively.

Deepak et al. [5] found experimentally that concrete with POFA replacement ratios of 0%, 5%, 15%, 25%, 35%, and 45% at 7 days achieved the following tensile strengths (in MPa), respectively: 1.15, 1.18, 1.1, 0.91, 0.59, and 0.38. At 28 days, the tensile strength (in MPa) for the same samples increased to the following: 1.78, 1.81, 1.91, 1.70, 1.12, and 0.8. It was found that cement with 15% replacement of POFA had flexural strength slightly higher than OPC alone. The tensile strength of concrete specimens is summarized in Table 3 [5].

Table 3. Tensile strength of concrete specimens at 7, 14, and 28 days of curing [5].with POFA

Concrete composition replacement	Average Tensile Strength (MPa)		
	7 day	**14 days**	**28 days**
0%	1.15	1.31	1.78
5%	1.18	1.32	1.81
15%	1.1	1.21	1.91
25%	0.91	1.03	1.70
35%	0.59	0.84	1.12
45%	0.38	0.6	0.8

Flexural Strength

Ranjbar et al. [29] showed that the 7 days flexural strength of POFA with 15% and 20% replacement ratio ranged from 5.12 to 6.19 MPa, while the 28 day flexural strength ranged from 5.46 to 6.90 MPa. The ratio of flexural strength to the corresponding compressive strength at 28 days is said to be comparable to conventional concrete. Generally, however, the incorporation of POFA in any volume has lowered the flexural strength compared to concrete specimens without POFA [29].

Sooraj [12] showed that flexural strength of cement replaced with 10% POFA is similar to the control mix. When POFA replacement was increased up to 20%, flexural strength increased, as well. Further increases in proportion of POFA was shown to cause a reduction in flexural strength of concrete [12]. For high strength concrete, Olowe and Adebayo [10] showed that the flexural tensile strength increased with age but reduced with the increase in Palm Kernel Ash replacement. The flexural strength at 28 days was 3.94 MPa for control concrete specimens, while concrete with 25% and 50% Palm Kernel Ash replacement ratios reached a flexural tensile strength of 2.62 and 2.44 MPa respectively.

Deepak et al. [5] studied the following POFA replacement ratios: 0%, 5%, 15%, 25%, 35%, and 45% at 7 days curing. The specimens achieved the following compressive strengths respectively (in MPa): 2.01, 2.02, 1.96, 1.78, 1.21, and 0.85. At 28 days, the compressive strength (in MPa) increased to the following: 3.7, 3.97, 4.31, 3.68, 2.03 and 1.55. It was found that the flexural strength of 15% POFA replacement specimens was slightly higher than OPC control specimens. Table 4 shows the flexural strength of concrete specimens with POFA replacement ratios at 7, 14, and 28 days of curing [5].

Table 4. Flexural strength of concrete specimens at 7, 14, and 28 days of curing [5].

Concrete composition with POFA replacement	Average Flexural Strength		
	7 day	**14 days**	**28 days**
0%	2.01	2.98	3.7
5%	2.02	3.09	3.97
15%	1.96	2.82	4.31
25%	1.78	2.52	3.68
35%	1.21	1.53	2.03
45%	0.85	1.12	1.55

3. Conclusion

Eggshell and POFA are two widely available agricultural wastes in Malaysia. In order to solve the disposal problem of these wastes, both materials have been studied as hybrid biofillers in concrete mixture, an alternative replacing Ordinary Portland cement. By using POFA and eggshells as concrete biofillers, the construction industry moves closer to achieving sustainability. Results of research studies show the validity of this approach and the potential for further successes in sustainability using eggshell and POFA, together in concrete mixtures, as partial cement replacement.

4. References

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