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Mechanical properties and acid resistance of oil palm shell lightweight aggregate concrete containing coal bottom ash

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ABSTRACT

Excessive use of natural river sand causes degradation of river environment scenery and water quality as well as certain flora and fauna in the area. At the same time, continues generation of by-product from palm oil industry and coal power plants namely oil palm shell and coal bottom ash calls for the utilization of these waste in material production rather than disposing it as waste. The present research investigates the mechanical properties and acid resistance of oil palm shell lightweight aggregate concrete containing coal bottom ash as partial sand replacement. Four types of concrete mixes were casted by using coal bottom ash as partial sand replacement from 0%, 10%, 20%, and 30% by weight of sand. All specimens were air cured until the testing age. The compressive strength and splitting tensile strength of concrete were tested at 7, 28 and 60 days. The resistance of specimen against acid attack was evaluated by measuring the mass loss and compressive strength after concrete cubes exposed to sulphuric acid solution. The results show that OPS lightweight aggregate concrete exhibit higher compressive and splitting tensile strength also enhanced acid resistance upon inclusion of 10% of coal bottom ash as sand replacement.

1. Introduction

World demand for palm oil increased annually because of its multipurpose use such as for cooking and cosmetic products. Nowadays, Malaysia, Indonesia and Thailand are among the world largest palm oil producer [1]. Malaysia being the second largest producing country globally [2], also facing challenges in managing the solid wastes from the industry. Among the wastes disposed by this industry are empty fruit bunch, oil palm shell, palm oil clinker and palm oil fuel ash. The waste dumping causes undesirable impact to the surrounding namely environmental pollution and habitat loss for living things [3]. Expansion in production causes increment in quantity of palm oil waste generated [4,5]. An estimated 2.6MT of solid waste is produced annually [6]. Oil palm shell waste has been discovered its potential to be used environmental friendly lightweight aggregate [7,8] in concrete because of its mechanical properties and durability performance [9].

Other than palm oil industrial waste, the aggregate supplying industry namely sand mining and granite quarrying for production of concrete that is used in the increasing construction projects also affects the environment. Sand mining activities to supply sand for construction causes negative effect to the river environment [10]. The on-going mining activities pose the risk of resources depletion [11] and destroy the environment [11,12,13,14]. The stone harvesting from the hills which needs removal of trees and plants prior to quarrying activity destroy the green forest contributing to global warming issues. The destruction of plants and habitat also affect the ecosystem. The production of coarse aggregate granite also

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generates quarry dust in finer size [15] which pollutes the surrounding [16]. Thus, utilization of local waste materials as an alternative material to reduce the depending on both natural sand and granite aggregate would be rewarding to the environment as well as the community. Additionally, this approach would save the land from being turned to waste dumping area [17].

At the same time, the local coal industry that operates to supply energy is generating by-products namely fly ash and coal bottom ash. American Coal Ash Association [18] reported that in 2016 about 37.25% were used from 10MT generated at the plant. The disposal of more than 60% of the ash definitely would have consumed extra cost and management tasks. The dumping of unused coal bottom ash is expensive [19]. The limited availability of disposal area and environmental hazards causes the disposal of this material become a problem [20]. The coal bottom ash which consist mainly silica, alumina and iron [21] have characteristic that enables it to be used as sand and coarse aggregate in concrete [22]. It is suitable to be used as aggregate replacement for concrete and masonry block production [23,24]. However, its use as sand replacement for construction material production is rare [25]. Therefore, the present research investigate the effects of coal bottom ash as partial sand replacement on the mechanical properties and acid resistance of OPS lightweight aggregate concrete.

2. Experimental work

The experimental work involving of three stages. The first stage is the preparation of material and its properties. At the second stage, the concrete mixing specimens were prepared to ensure all the specimen follow the standard requirement. At the third stage, all the specimen were tested.

2.1. Materials

Cement, oil palm shell, river sand, coal bottom ash, water and superplasticizer were used for concrete specimens. Orang Kuat brand, one of the common brand Ordinary Portland cement were used as the binder. Oil palm shell were supplied by nearby palm oil mill. The OPS then been dried for 24 h and were used as coarse aggregate replacing the granite aggregate to make the specimen. The properties of OPS in Fig. 1 are presented in Table 1. Coal bottom ash (CBA) illustrated in Fig. 2 was used as partially fine aggregate replacement. CBA passing 2 mm sieve were used. The chemical composition of CBA is presented in Table 2.

Table 1
Physical characteristics of OPS.

Properties	OPS
Maximum aggregate size, mm	10
Shell thickness, mm	0.6–4.6
Los Angeles abrasion value, %	5.4
Aggregate impact value (AIV), %	15.9
Aggregate crushing value (ACV), %	9.22
Specific gravity (SG)	1.29
Fineness modulus	5.696
24 hr water absorption, %	36.25

Fig. 2. Coal bottom ash.

Table 2
Chemical composition of CBA.

Composition	%
SiO_2	34.7
Al_2O_3	12.3
Fe_2O_3	9.93
CaO	5.60
MgO	0.79
Na_2O	0.75
K_2O	0.88
TiO_2	0.86
SO_3	2.75

Fig. 1. Oil palm shell at the factory.

2.2. Mix proportion and concrete preparation

The concrete mix of Grade 20 was prepared using trial mix method. In this research, four mixed were used in OPS lightweight concrete specimen with different amount of CBA as partially sand replacement. The quantity of coal bottom ash (CBA) used was varied from 0%, 10%, 20%, and 30% by weight of sand. The amount of cement, oil palm shell and superplasticizer were kept constant. The quantity of water was adjusted to maintain the same workability for all mixes. Table 3 shows the concrete mix proportion used in this research. All specimen were prepared in size cubes (100x100x100) mm. All specimens were water cured inside the laboratory up to 28 days before testing.

2.3. Testing procedures

The compressive strength testing and splitting tensile strength determination were adhering to BS EN 12390–3 [26] and ASTM

Table 3
Concrete mix proportion (kg/m^3).

Mixes	Cement	Oil Palm Shell	Coal Bottom Ash	Sand	Superplasticizer
CBA- 0	500	300	0	700	5
CBA-10	500	300	70	630	5
CBA-20	500	300	140	560	5
CBA-30	500	300	210	490	5

C496 [27] respectively. The acid resistance of concrete were determined by measuring the mass loss and compressive strength of cubes after immersed in sulfuric acid solution, similar to experimental method of previous researchers [28].

3. Results and discussion

3.1. Compressive strength

As can be observed in Fig. 3, all specimens exhibit higher strength as curing time prolonged. The 7 days compressive strength test result is between 17.32 and 19.67 MPa. The compressive strength for specimens are between 17.54 and 24.6 MPa for 28 days. Meanwhile for 60 days, the strength are between 20.77 and 25.8 MPa. Evidently, the use of 10% CBA improves the concrete strength due to the pozzolanic effect of fine ash particles that present in the waste added in the mix. The beneficial effect of pozzolanic reaction by coal bottom ash towards densification of concrete internal structure has also been reported by past researchers [29]. Similar trend is also observed in high strength when CBA is used as partial sand replacement [30]. Use of CBA at 20% and 30% causes concrete strength reduction. The higher water absorption characteristic of CBA particles owing to its porous nature compared to dense river sand particles reduces the concrete mix workability that impedes proper compaction process. As a result, concrete with larger quantity of CBA is more porous and exhibit lower strength value as reported by [30].

3.2. Splitting tensile strength

Fig. 4 shows the OPS lightweight aggregate concrete exhibit increment in the splitting tensile strength when 10% is used to replace the sand partially at all curing age. However, further replacement causes the concrete to experience strength reduction. Previous researcher [30] also noted the positive strength enhancement of concrete upon use of suitable quantity of CBA. Presence of high quantity of SiO_2 in fine CBA particle in the concrete that is subjected to continuous water curing promotes the occurrence of pozzolanic reaction. This results in formation of extra CSH gel creating a denser microstructure with higher strength. Past researcher [31], pointed out that the use of CBA promotes pozzolanic reactions within the concrete and increase the strength.

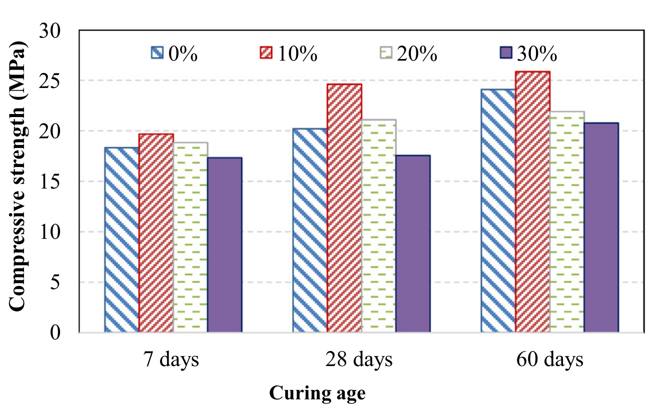

Fig. 3. Compressive strength result.

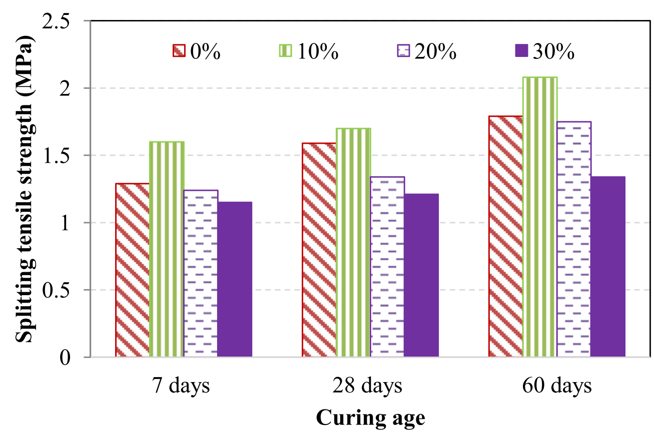

Fig. 4. Splitting tensile strength.

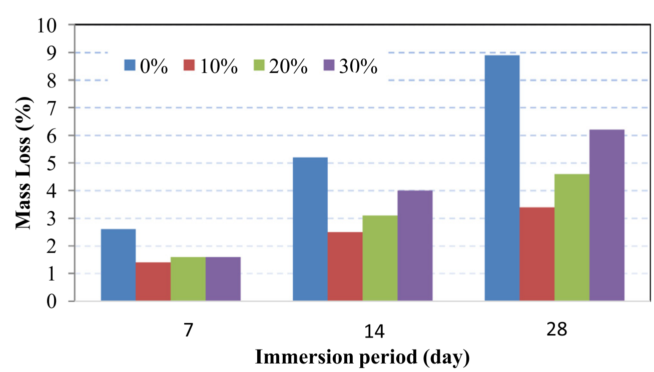

Fig. 5. Mass loss of concrete specimen after immersed in sulphuric acid solution.

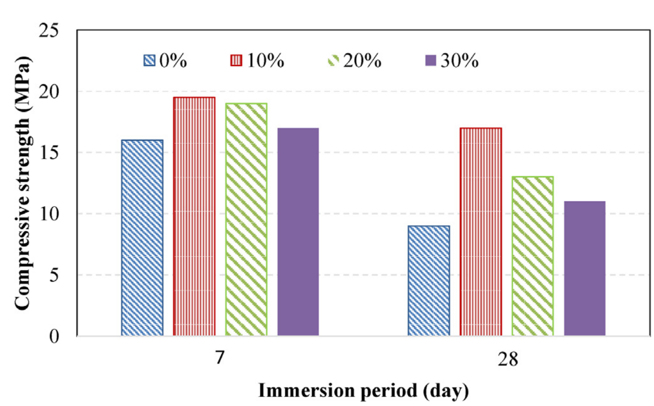

Fig. 6. Compressive strength of concrete specimen after immersed in sulphuric acid solution.

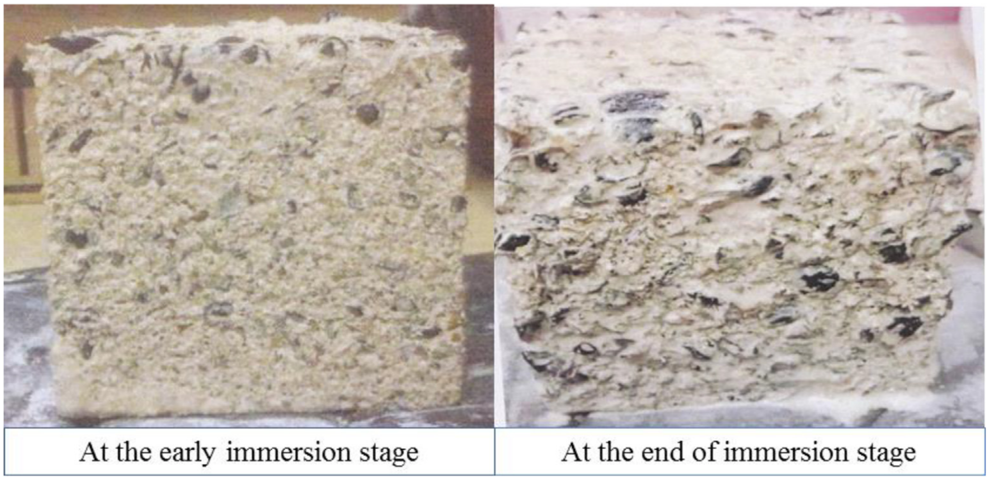

Fig. 7. Physical deterioration of plain concrete specimen immersed in sulphuric acid solution for 28 days.

3.3. Acid resistance

Figs. 5 and 6 show that the utilization of coal bottom ash affects the durability performance of concrete immersed in sulphuric acid solution. Generally, all concrete experience mass loss and strength reduction as the immersion time increases. Prolonged exposure to acidic environment causes the concrete to experience more reduction in mass and strength [32]. As can be observed in Fig. 7, concrete placed in immersed the acid solution undergoes physical change owing to the acid attack. However, it is important to highlight that specimen containing coal bottom ash exhibit lower mass loss and better compressive strength than plain specimen at all immersion period. Remarkably, specimen with 10% coal bottom ash experiences the least mass loss and highest compressive strength. The pozzolanic effect caused by the presence of coal bottom ash increases the denseness of the concrete internal structure which enhances its durability to acid attack. The enhanced acid resistances of concrete with certain amount of CBA were reported by past researcher [30].

4. Conclusion

The present finding shows OPS concrete with coal bottom ash up to 10% replacement has the potential to be used in concrete production. Further research need to be conducted to explore the performance of concrete containing mechanical activated or alkali activated coal bottom ash. Success in utilizing this coal ash in construction material production would reduce quantity of waste thrown and save the usage of land for waste dumping.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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