Materials Today: Proceedings 47 (2021) 282–285

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Mechanical and durability properties of treated oil palm shell lightweight concrete

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ARTICLE INFO

Article history:
Received 17 April 2021
Accepted 22 April 2021
Available online 11 May 2021

Keywords:
Oil palm shells
Coarse aggregate
Durability
Bond
Lightweight concrete

ABSTRACT

In this research study treated oil palm shells are used as coarse aggregate in producing lightweight concrete to examine the behavior of bond and durability properties. Oil palm shells having high absorption capacity, these are treated with silica-hydrogen compound admixture to minimize the absorption rate. These treated oil palm shells are used in making lightweight concrete. Prepared treated oil palm shell lightweight concrete is examined with non-treated oil palm shell lightweight concrete to examine the mechanical and durability behavior. Bond between the reinforcement and binder is examined by pull out test and the results are compared with non-treated oil palm shell concrete. Durability like permeability, sulphate attack is examined and compared. Laboratory experimental shows the use of treated oil palm shell for making lightweight concrete had better results than the non-treated oil palm shell concrete.

Selection and peer-review under responsibility of the scientific committee of the 12th National Conference on Recent Advancements in Biomedical Engineering.

1. Introduction

Concrete is the largest material that is consumed by the construction industry [1]. This industry consumes a large number of natural and non-renewable sources such as water, sand and gravels [2]. Global concrete industry roughly consumes 7.5 billion tons annually [3]. This reduces stone deposits and causes ecological imbalances [4]. Concrete is not an environmentally friendly material. Construction industry has a significant social, economic and environmental impact [5]. Using waste from the industries and the by-products available as waste can be used as raw materials as best alternative materials to achieve sustainable development of the concrete [6].

For the past 25 years, researchers used oil palm shells or palm kernel shells as lightweight aggregates as a percentage replacement of coarse aggregate for producing lightweight concrete [7]. Countries like South East Asia, Africa, America, India, Malaysia, Nigeria and Indonesia produce palm oil in the world. Malaysia produces nearly 4–5 million tons of oil palm shells waste annually as the Malaysian are the second-largest palm oil-producing countries in the world as reported by Shafigh et al., (2011) [8]. As these are from industrial waste with high quantity as a waste product, the initiative has been taken by the researchers to utilize them as alternative coarse aggregate in concrete [9].

One way of attaining sustainable and environmentally friendly structures is to use industrial waste as a construction material. Oil palm shells obtained from palm oil extraction process fromthe palm oil industry are a promising material and are also lightweight, which can be used as a replacement of coarse aggregate (gravel) in conventional concrete. OPS are found to absorb more water compared to gravel aggregates [10]. Water absorption test shows OPS have a water absorption rate of 20–24% which is 4–5 times higher than the gravel aggregates. Hence, surface treatment is carried out for OPS aggregates with silicon-hydrogen (Si-H) compound [11]. This surface treatment reduces the water absorption in OPS aggregate to a normal level. Treated OPS aggregates are designated as TOPS and non-treated OPS aggregates are designated as NTOPS [12]. Use of industrial waste aggregates in the making of lightweight concrete has numerous advantages than the use of other lightweight aggregates. Use of OPS as coarse aggregate in concrete not only decreases the density of the concrete but also

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https://doi.org/10.1016/j.matpr.2021.04.373
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the 12th National Conference on Recent Advancements in Biomedical Engineering.

improvement in strength which can be comparable with conventional concrete [13]. Conventional coarse aggregate replacement with OPS aggregate can minimise the industrial waste and is a better alternative for non-renewable conventional aggregate (gravel or granite). Lightweight aggregates other than OPS need to be manufactured or processed under elevated temperatures and need to be monitored step by step in every process of making [14]. OPS are only aggregates that are not manufactured or prepared and they are directly taken from industries. The effect of OPS lightweight concrete with conventional concrete is intended in the study. A detailed literature survey was carried out on the studies OPS lightweight concrete and their comparison with conventional concrete [15]. Muthumani M and Swamynadh V used industrial waste oil palm shells as coarse aggregate for producing lightweight concrete [16]. Oil palm shells are extracted after the production of palm oil from palm oil fruit. The maximum dry density of concrete is 1850 kg/m^3 when OPS are used as aggregate[1]. The density of OPS concrete is 22% lower than the conventional concrete. Concrete beams made with lightweight and conventional concretes show higher moment capacity in lightweight OPS concrete than in conventional concrete [17]. Palm kernel shells possess same hard characteristics as conventional aggregate. Conventional concrete and palm oil concrete shows similar flexural behaviour of reinforced concretes. The deflection of OPS concrete is similar to conventional concrete [18,19]. Effect of coating on palm oil clinker aggregate (POC) was studied by Swamy Nadh V (2017). Palm oil aggregates are highly porous in nature. These are coated with palm oil clinker powder to minimise the void percentage in aggregate [20]. Workability of POC is improved after the surface of the POC is coated with POC powder. Coated POC aggregates were used in the making of concrete and examined for compressive strength. A decrease of about 20–30% in compressive strength is observed in coated POC lightweight concrete of about 20–30% compared to non-coated POC concrete. Splitting tensile strength is similar in both the lightweight concretes. Decrease in flexural strength of coated POC concrete of approximately 20%. Coating with POC powder on POC aggregate can improve the chloride-ion resistance of lightweight concrete at 12–70% as compared to non-coated POC aggregate concrete.

2. Methodology for producing treated oil palm shell lightweight concrete

OPS have different properties as compared to conventional aggregate. The methodology followed for oil palm shell lightweight concrete is shown in Fig. 1. In this study, the following steps are considered to produce oil palm shells lightweight concrete and conventional concrete.

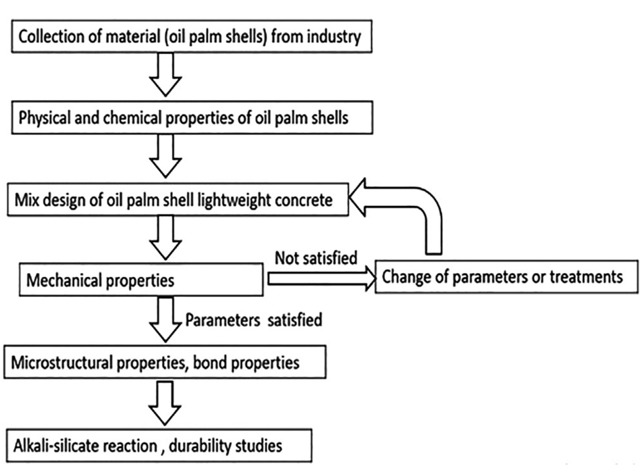

Fig. 1. Methodology to produce treated oil palm shell lightweight concrete.

First is the collection of oil palm shells, from the palm oil industry and conventional aggregate from manufactures. Materials so collected are processed and cleaned. As these are from industrial waste any kind of toxic chemicals may be present on the surface of the aggregate. Next step is to find physical properties. Physical properties of OPS aggregates and conventional aggregates are evaluated and compared. Physical properties like specific gravity, water absorption, aggregate impact value, elongation index, flakiness index are evaluated for conventional aggregate and oil palm shell aggregates. Next step is to do mix design for both the concretes i.e., conventional concrete and oil palm shell concrete. The mix design of oil palm shell lightweight aggregate is carried out according to the previous research studies. Conventional concrete mix design is done according to IS 10262:2009.

Next step is to evaluation of mechanical properties of OPS concrete and conventional concrete. Concretes prepared are cured according to the standards. Cured concretes are subjected to mechanical testing (compressive strength test) to compare the mechanical behaviour. After comparing the results of oil palm shell lightweight concrete with conventional concrete, if results are satisfied next step is microstructural properties of concrete. If results are not satisfied, change in parameters of lightweight concrete is carried out and again the process is continued from mix design procedure. Next step is to find microstructural properties and bond properties of conventional concrete and OPS lightweight concrete. In microstructural properties, ITZ thickness and bond characteristics of both the concretes are studied. Durability properties of lightweight concrete and conventional concrete are carried out in the next step. The durability of concrete is an important parameter. Permeability and porosity of the OPS concrete are carried out and explained. Alkali-silicate reaction is an important study in the durability of concrete. Oil palm shell is used as a new constituent in the concrete and it may be subjected to high silica or it may contain other chemical compositions. Oil palm shells are to be studied for the alkali-silicate reaction process. Chloride attack and sulphate attack is also studied in this step.

3. Properties of materials used in this research

The specific gravity of oil palm shells is 1.24. Malaysian oil palm shell has specific gravity of 1.37 and the specific gravity of the OPS never crossed more than 2.Water absorption rate in convention aggregate is 4 to 5% whereas in oil palm shell lightweight aggregate used in this research it is 25%.OPS aggregates of size 10 mm are used to prepare the lightweight concrete. Porosity of OPS aggregate is 29.8%. Edmund et al. 2014 reported that oil palm shell has porosity of 28%. High porosity of OPS is due to the macro pores in the OPS aggregate.

3.1. Physical properties for treated OPS.

Maximum grain size of OPS aggregate used in present study is 12 mm whereas Malaysian OPS has 13 mm. Bulk density of OPS aggregate is 350–480 kg/m^3 and this is the reason for lower density of concrete [21]. Water absorption of OPS used in this study and Malaysian OPS are similar. Thickness of OPS used in this research is 3 mm whereas Malaysian OPS ranges from 0.3 to 8 mm. Flakiness index and elongation index are similar for OPS aggregates used in this research and Malaysian OPS but higher than conventional aggregates [22-24].

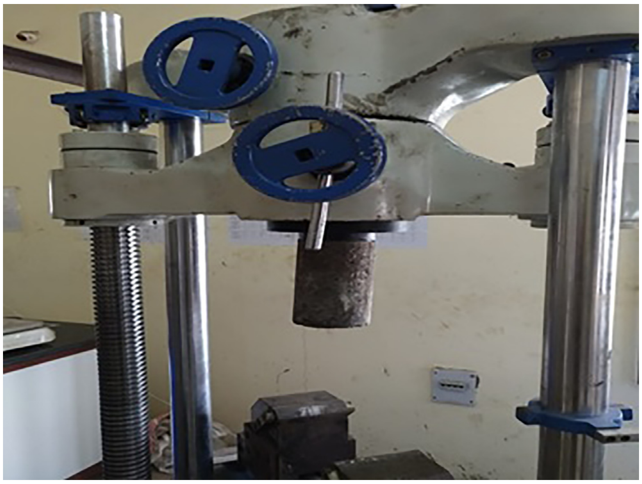

Fig. 2. Pull out test for treated lightweight concrete.

Fig. 3. Specimen representing concrete and reinforcement bar after pull out test.

3.2. Design of the lightweight concrete mix

Two types of concretes, lightweight concrete and conventional concretes are investigated with different mix proportions for comparisons of compressive strength. Conventional concrete is designated as normal weight concrete (NWC) whereas oil palm shell lightweight concrete is named as (LWC) in this trail mix. Samples are prepared and cast in cube moulds of size 150X150X150 mm and cylindrical moulds of size 100 X 300 mm are prepared to compare for mechanical strengths of concretes. Fig. 2 exposed Pull out test for treated lightweight concrete [25].

Oil palm shells consume more water as compared to conventional aggregate. OPS are soaked in water for 24 h before the preparation of lightweight concrete. Soaked oil palm shells are wiped with dry cloth after 24 h and then used as coarse aggregate in lightweight concrete in surface dry conditions [26-28]. The prepared concrete is transferred to respective moulds for examination and kept in room temperature for 24 h. Samples prepared are demoulded after 24 h and cured for 28 days in water [29-31]. After 28 days of curing the samples are taken out from the water and are prepared for testing. The mix design details of lightweight concrete and normal weight concrete given below.

- Surface of OPS is treated organosilane coating.
- Water/cement ratio is 0.45.
- Mix ratio is 1:1.8:0.75.
- Surface of the TOPS concrete is similar to NWC.
- Compressive strength is 28.9 MPa.

Fig. 3 showed specimen representing concrete and reinforcement bar after pull out test. Stress between the reinforcing bar and the surrounding concrete along the embedded length of the bar.

$$S = P_{max}/(\pi \times L \times d)$$

P_{max} = maximum pull out load (26.7).
d = diameter of the bar (12 mm).
L = Embedded bar length (100 mm).

Bond strength of TOPS concrete is 7.08 MPa. Similar bond strength of 8.12 Mpa is noticed in conventional concrete.

4. Conclusions

- Key issue 1: As OPS is highly water absorption material; this is treated with water absorption coating to minimize the water absorption rate from 25% to 8%.
- Key issue 2: Desirable aggregate impact value is obtained after the OPS treated with water absorption coating. Aggregate impact value of TOPS aggregate is 21.6%.
- Key issue 3: Compressive strength is improved when using TOPS as coarse aggregate in lightweight concrete. Compressive strength of TOPS concrete is 28.6 MPa.
- Physical bonding is improved between the aggregate to matrix phase with TOPS.
- Key issue 5: Bond between the aggregate to matrix phase is studied in TOPS and conventional concretes. Similar bonding is noticed in both the concretes.
- Key issue 6: Expansion of concrete is within the ASTM limit as the alkali-silicate reaction is concerned. It is below 0.2%.
- By using TOPS as coarse aggregate in concrete, density reduced by 28% which represents lightweight concrete.
- TOPS are better alternate material for replacement of coarse aggregate in concrete.
- Durability properties of TOPS concrete are in permissible limits as ASTM is concerned.

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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Further Reading

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