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Research Article

Structural Behavior of Nanocoated Oil Palm Shell as Coarse Aggregate in Lightweight Concrete

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Oil palm shells (OPS) are mechanical waste that is utilized as coarse aggregates in lightweight concrete. These OPS have shape and strength like conventional aggregates yet the substantial made with these OPS invigorates a limit of 18 MPa. The characteristic strength which must be utilized in structures is seen to be around 25 MPa to 30 MPa. Considering the strength as one of the boundaries for design to be sturdy, the OPS are surface-covered with nanosilane compound. This nanosilane covering goes about as infill on the outside of the aggregates and holds the concrete paste as traditional cement. Operations are permeable in nature; their inner construction has permeable design which makes the aggregates frail. Nanosilane coatings go about as holding between the concrete stage and aggregate stage and hold the substantial solid. In the present examination, mechanical and underlying conduct of nanocovered oil palm shell lightweight concrete is contrasted with that of regular cement. Nanocovered oil palm shell lightweight substantial shows comparative strength as customary cement and decrease in nonsustainable wellspring of energy in oil palm shell lightweight concrete. Supplanting of customary cement with oil palm shell concrete addresses the modern waste which can be utilized for making concrete solid and solid. Morphology and material portrayal of oil palm shell and ordinary aggregates are investigated.

1. Introduction

One the main structure materials in structural designing is primary cement. Lightweight aggregates (LWA) are by and large used, being developed in regions these days which shows monstrous advantages [1]. Thickness contrasts between lightweight concrete (LWC) and normal weight concrete (NWC) are about 28% [2]. Usage of lightweight concrete being developed lessens the seismic effect on the development and thickness contrasts which shows the traditionalist arrangement of essential people like shaft and fragment. Usage of lightweight concrete decreases the utilization of steel in structure. Reduction in thickness of significant saves improvement and transportation cost, which may prompt extension in stories and longer ranges in platforms and abatement size of the essential people. Concrete made with lightweight cement to convey essential concrete should be hidden lightweight concrete and moreover called as lightweight concrete (LWC) [3]. There is liberty of basically lower unit weight than that of conveyed using rock or squashed stone. As side-effects from adventures, for instance, oil palm shells, reused plastic, and reused flexible are similarly used as lightweight sums in making of lightweight cement. Lightweight totals conveyed in turning

Figure 1: Oil palm shells.

Table 1: Physical properties of aggregates used in this research.

Properties	Oil palm shell	Nanocoated oil palm shell	Conventional aggregate [11]
Aggregate size (mm)	12	12	40
Thickness (mm)	0.4–9	0.4–9	—
Bulk density (kg/m^3)	580	580–590	1430–1570
Specific gravity (SSD)	1.27	1.25–1.28	2.60
24 h water absorption (%)	23	8	2–4
Aggregate impact value (%)	29.5	21.6	17.8
Porosity (%)	27%	18%	15%

broiler are expanded soils; shales should be LECA sums [4]. Lightweight aggregates made by sintering are said to by AGLITE sums. Lightweight aggregates made by water fly or slags stretched out unequivocally should be FOAMED lightweight sums, while sintered squashed fuel flotsam and jetsam sums should be LYTAG aggregates.

Genuine properties of OPS, for instance, water ingestion, surface area, thickness, and influence regard were finished by Barton et al. (1998) (using ACI 211.2, ASTM D3398, and ASTM C127 (ACI 211)). By far, most of the examinations in the past found interstitial change zone (ITZ) or bond direct of complete to network in lightweight concrete with different lightweight sums as uncovered [5]. All the LWA shows assorted lead up on their making cooperation and the conditions. Right when the LWC differentiated from NWC, the bond strength of NWC is higher and stood out from that of LWC [6]. However, few examinations uncovered that there is essentially indistinguishable bond strength among LWC and NWC.

Artificial aggregates like shale and broadened mud and record which are made by rotatory heater measure have been used for numerous years. These lightweight sums helps in the decline in additional weight, decline in sizes of the people, and warm security. Concretes produced with these lightweight aggregates as shown in Figure 1 had thickness of 1400-1750 kg/m^3 with the most outrageous compressive strength of 18-25 MPa. According to ACI 318-R, lightweight concrete conveying more than 25 MPa should be basic lightweight concrete. Aggregates which are used for numerous years cannot make compressive strength more than 25-30 MPa according to trained professionals. Extension of admixtures and blended sums can convey significant strength up to 30-33 MPa [7]. Various experts used fly flotsam and jetsam, GGBS, silica smoke, and rice calm remaining parts as significant replacement of cement. Various experts used coconut shells, egg shells, and various sorts as replacement of coarse aggregate almost completely. All of the assessments address that any displaced constituent material concrete can be used remarkably for building nonessential parts in the turn of events.

Bonding of concrete has a critical essential limit when we use a new material. The holding power among concrete and steel is fundamentally a direct result of the grasp between network (cement, sand, and water paste) and aggregate. Cooperation of holding rises up out of crushing of all out stage to harden stick and significant lattice to developing steel, mechanical dock of ribs against the considerable surface as nitty gritty [8]. As made lightweight sums or reused aggregates (RA) have higher flakiness document, it animates more security than standard concrete.

It is represented that open OPS in India can be used as a replacement of coarse absolute in concrete to make the lightweight concrete after genuine treatment of OPS complete as itemized by Swamy Nadh and Muthumani [9]. The place of the assessment is to make surface-treated OPS lightweight concrete with diminished ITZ thickness. Late researchers saw that reused aggregates show higher ITZ thickness than the normal significant which is a direct result of the genuine properties of reused sums used for making of concrete [10]. Smaller than usual essential assessment of treated oil palm shell lightweight concrete and nontreated oil palm shell lightweight concrete are thought of and differentiated and customary concrete. ITZ thickness in all of the three concretes is dissected; mineralogical properties are concentrated with the help of XRD assessment.

2. Materials Used and Methodology

Materials used in this research are OPS, conventional aggregate, cement, sand, and some fillers to make the concrete durable and strong to hold the compressive force acting on that. Nanocoat is used to fill the pores of the OPS aggregate and to create good bonding between the aggregate to cement phase. The physical properties of OPS, nanocoated OPS, and conventional aggregate are given in Table 1. Water absorption of OPS (23%) is higher than conventional concrete (4-5%), whereas nanocoated OPS (8%) has similar water absorption to conventional concrete. This is due to the fact that nanofillers of the coating act as filler on the voids of the OPS aggregate; this reduces the water absorption level in the coated OPS aggregate.

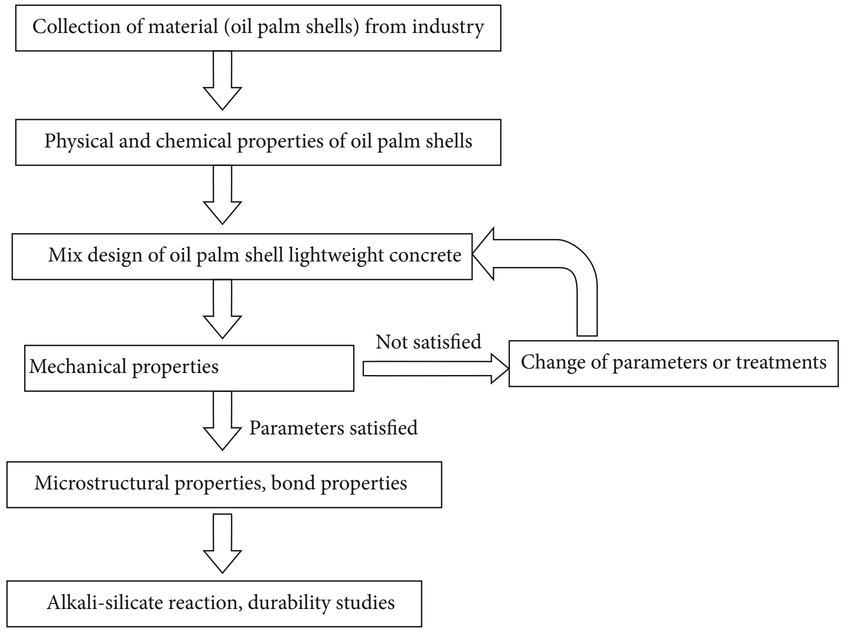

Figure 2: Block scheme diagram.

Table 2: Mix design for OPSC (oil palm shell concrete) and CC (conventional concrete).

Mix	Cement (kg)	Water (liter)	W/C (ratio)	Sand (kg)	Coarse aggregate OPS (kg)	Coarse aggregate Gravel (kg)	Slump (mm)	Density (kg/m^3)
OPSC	380	152	0.4	750	—	1080	60	2362
CC	480	192	0.4	715	382	—	95	1769

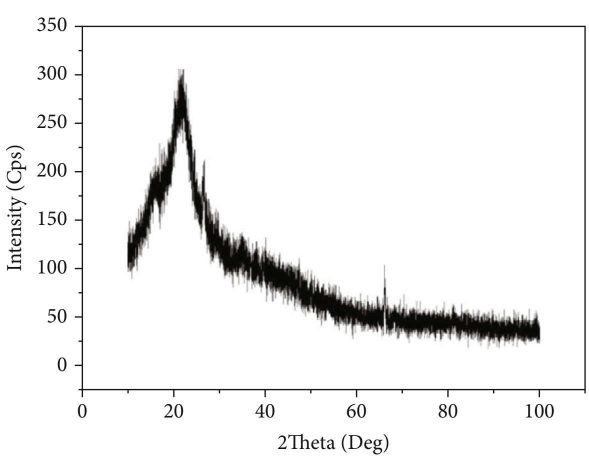

Figure 3: XRD analysis of OPS aggregate.

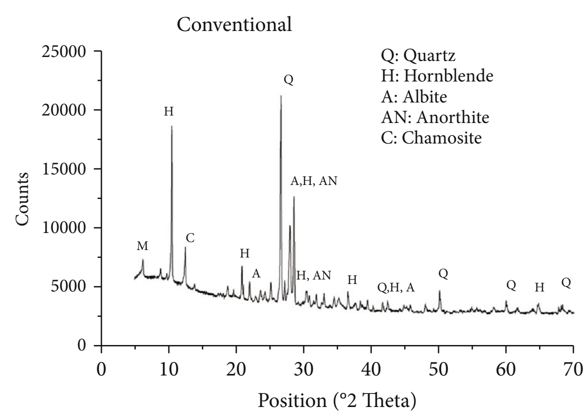

Figure 4: XRD analysis of conventional aggregate.

2.1. Experimental Procedure. Oil palm shells are prone to voids as these are from industrial waste toxic chemicals which are observed on the external part of the shells. For using these OPS as replacement of coarse aggregate in the concrete, it should be treated with water. A unique methodology is adopted in this research paper to use OPS as coarse aggregate in concrete. As shown in Figure 2, a stepwise procedure is conducted to make the OPS concrete strong, durable, and resistant to chemical attack. A special mix design is considered to make the OPS concrete as these absorb more amount of water as mentioned by Vandanapu and Krishnamurthy [12]. OPS aggregates are soaked in water and dried to room temperature. These have very less weight as compared to conventional aggregate as their specific gravity is 1.2. The quantity of aggregates used in OPS concrete is more compared to conventional aggregate.

The concrete made with OPS is dried in room and even in oven temperature to make the concrete completely dry by 28 days. The dried concrete is taken for testing. Once the test results are satisfied, remaining samples were tested under durability aspect. If the results for the above concrete are

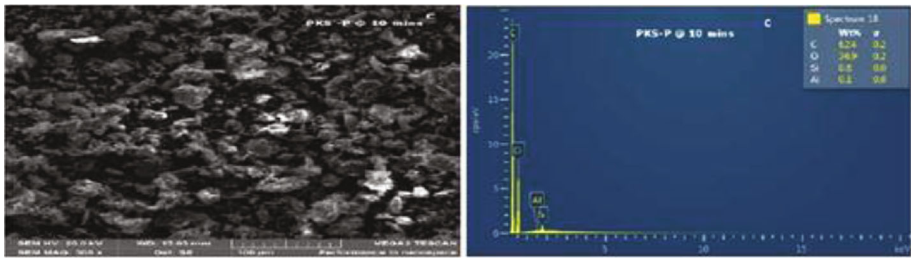

Figure 5: EDX analysis of nanocoated OPS aggregate powder.

not satisfied, reconsideration of mix design and well as special treatments is done accordingly.

Conventional concrete (CC) with natural aggregates is made with water/cement ratio of 0.35. Conventional concrete cubes and cylinders are casted and cured for 28 days. Cured concrete is tested under a compressive testing machine to know the mechanical behavior of concrete. Measured mechanical properties are compared with those of OPS concrete.

Concrete made with OPS is surface dried and examined for surface texture. There is uneven texture of OPS concrete; this is due to the more water absorption of OPS as their internal structure is completely with pores as mentioned by Shafigh et al. [13]. The OPS concrete seen in Figure 2 is leached, and shells are coming out forming the edges. When the concrete is demolded after 28 days of curing, the edges of the OPS concrete are collapsed and the internal structure of the concrete is somewhat wet. As the OPS concrete is tested under UTM capacity of 200 kN, the maximum compressive strength of the concrete is around 15 MPa [14]. This shows how the concrete is poor in compression as compared to conventional concrete.

Variety in concrete substance for OPSC and CC can be seen in Table 2. The same water/concrete proportion is utilized for making OPSC and CC. Expansion in concrete substance in LWC is because of the raised state of the oil palm shells which required greater amount of glue stage to fill the holes in the substantial. So the concrete amount is more when contrasted with ordinary cement [15]. Droop worth of OPSC is 95 mm though in CC it is 60 mm. Varieties in droop esteem are because of the thickness of the substantial and framework content. Thickness of lightweight cement is 28% less when contrasted with ordinary cement.

3. Results and Discussions

3.1. XRD Analysis. Mineralogical properties are carried out for OPS to examine the internal structure. This method is taken into consideration to understand the behavior of the OPS aggregate, as the OPS concrete is shown to have less compressive strength than the ordinary concrete [16]. Examination of OPS is only done because the unknown constituents of the OPS concrete are OPS, as the remaining constituents of the concrete are known and examined by many researchers worldwide [17].

Figure 3 shows the XRD analysis of OPS aggregate; the figure clearly shows the amorphous behavior of aggregate, like glassy structure. This kind of amorphous behavior makes the aggregate break easily under compression. The intensity peaks of OPS are only observed in 21.3 2θ angle which represents silicon dioxide. One more peak is observed around 69 2θ angles which represent iron oxide in XRD analysis of OPS aggregate [18]. This results in poor workability and leads to less compressive strength. These peaks in OPS are not crystalline as conventional concrete. Figure 4 shows the XRD analysis of conventional concrete. Several peaks are observed in XRD analysis of conventional concrete; these peaks show different mineralogical properties of conventional aggregate [11]. This type of crystalline peaks leads to higher compressive strength and more durable to environment.

Figure 6: Internal structure of nanocoated OPS concrete.

3.2. Nanocoated OPS EDX Analysis. Nanocoating is sprayed on the surface of the OPS aggregate to fill the pores on the surface of the aggregate. Choosing of the nanocoating is finalized after many coatings are made with wax, sintering and applying filler coat on the surface of the OPS aggregate. The aggregates are coated with nanoorganosilane compound which fills the surface aggregate pores and makes proper bonding with cement matrix. This coating is spared at 1 : 10 nanosealer-to-water ratio and evenly sprayed on the surface of the aggregate [19]. These aggregates are dried in room temperature for 24 h and oven dried for 8 h. Nanocoated OPS are examined under EDX analysis, and mineralogical properties are taken out. Figure 5 shows the OPS shell as well as OPS powder, and crystal peaks that formed are observed which represent the elements of conventional aggregate. Carbon, oxygen, calcium, potassium, iron, and magnesium and some other elements are observed in the OPS EDX peak [20].

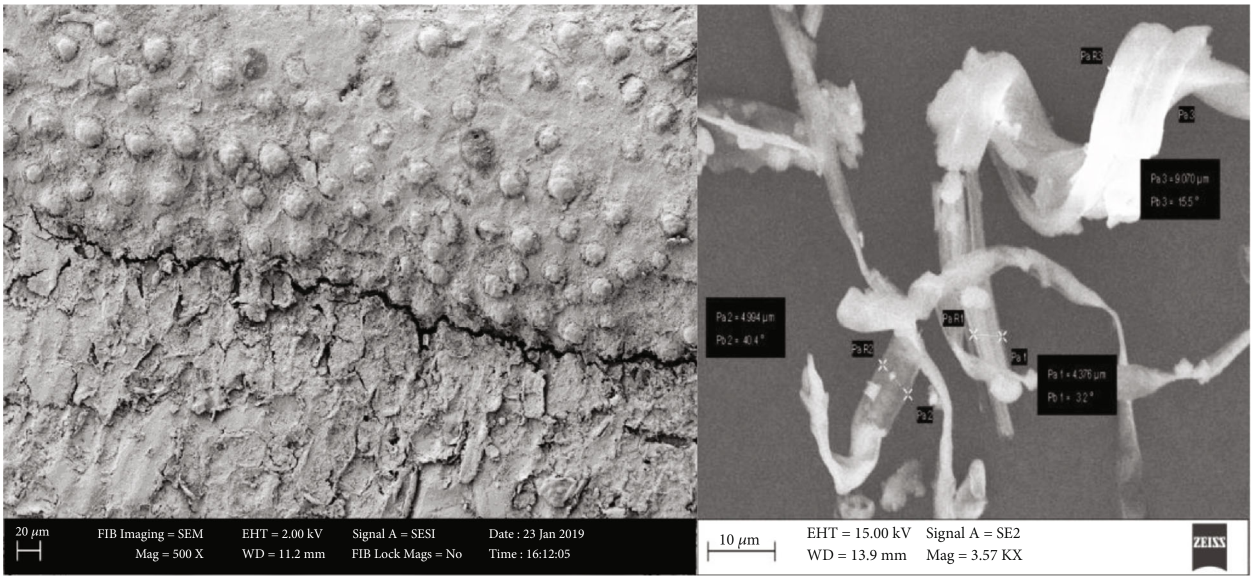

Figure 7: Nanocoated OPS aggregate and size of the OPS fiber.

3.3. Microstructural Analysis of Nanocoated OPS Aggregate and OPS Powder. Observation of the microstructural properties of nanocoated OPS aggregate is carried out to examine the internal bonding between aggregate to the cement paste. Bonding is the major criterion for the concrete to be strong. Scanning electron microscope (SEM) examination has shown the morphology of nanocoated OPS aggregates: conventional concrete with ITZ thickness less than 400 μm, nontreated OPS concrete with ITZ thickness more than 600 μm, and treated OPS concrete with ITZ thickness of maximum 400 μm. Operation aggregates are analyzed with SEM gear under electron high pressure of 300 V to 30 kV at the profundity of 4 to 30 mm [21]. SEM examination of nanocoated OPS totally uncovers the interior design with permeable and heterogeneous construction as displayed in Figure 6. Inward construction is for the most part permeable and has a pore size of 0.5 to 15 micrometers. This offers admittance to the inward surface of the particles to burn-through more water [22].

Microstructural analysis of OPS after coating with nano-siliceous material is shown in Figure 7. This shows that the pores on the surface of the OPS are filled with nanocoatings as shown in Figure 7. Micropores are filled with nanocoating; these pores have a size of 10 micrometers to 12 micrometers. Filled pores are seen on top of the OPS aggregate with bubbles. This improves the bonding between OPS and cement paste. This shows improvement in the interfacial transition zone of the nanocoated OPS concrete [23].

Water absorption of nanocoated oil palm shells is 25% whereas it is 5% for conventional aggregate. The binder is not sufficient to mix with concrete due to higher absorption rate in OPS aggregate. Aggregate impact value of OPS aggregate is not in the range of standards for making the concrete. XRD analysis of OPS aggregate shows a lower percentage of Al_2O_3 as compared to conventional aggregate. Al_2O_3 is a hard material composition which is responsible for the strength of the aggregate and also for aggregate impact value [24]. SEM images of OPS aggregate show the pore diameter of 0.5-15 micrometers whereas conventional aggregate has a pore diameter of 2-5 micrometers.

Table 3: Compressive strength of concrete.

Concrete type	W/C ratio	Compressive strength (MPa)		
		7	14	28
OPS concrete	0.50	7.4	8.7	10.4
	0.55	8.6	9.5	11.6
	0.60	9.7	11.4	13.7
Nanocoated OPS concrete	0.32	16.8	18.1	24.6
	0.38	17.1	22.2	2543
	0.42	15.8	23.4	28.6
Conventional concrete	0.30	15.6	24.3	28.1
	0.42	16.8	24.6	26.6
	0.47	17.5	24.2	28.7

Table 3 shows the mechanical behavior of nanocoated OPS concrete, conventional concrete, and OPS concrete. In conventional concrete, the compressive strength for 28 days is 27 MPa. The compressive strength for nanocoated OPS concrete is 26.7 MPa whereas OPS have a maximum compressive strength of 12.6 MPa. This shows improvement in OPS lightweight concrete after the coating with nanosilane coating. This coating improved the bonding between the OPS aggregate and the cement paste, so there is higher compressive strength noted in coated OPS concrete than in non-coated OPS concrete [25].

3.4. Alkali-Silicate Reaction for Nanocoated OPS Concrete. Materials which are under the effect of environment are exposed to different chemicals; in this, one of the most reacted chemicals in concrete is reactive silica. This reactive silica cracks the concrete due to thermal stresses due to

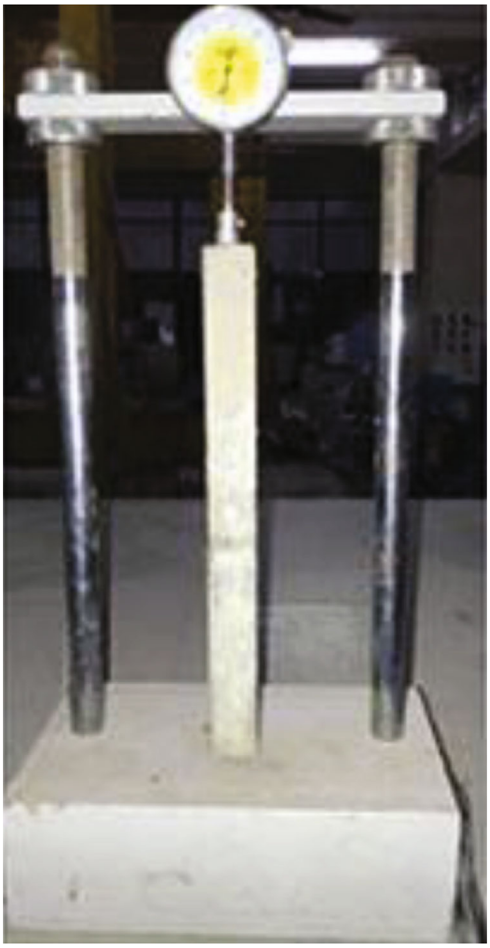

Figure 8: Alkali-silicate reaction of nanocoated OPS concrete.

Table 4: Expansion of nanocoated OPS concrete samples.

Sample	Aggregate	Expansion after 90 days (mm)
A1	OPS coarse	0.0415
A2	OPS coarse	0.0435
A3	OPS coarse	0.0442
B1	OPS fine	0.031
B2	OPS fine	0.035
B3	OPS fine	0.0325

increase in pH value [26]. This causes expansion of concrete which leads to cracking. As OPS are exposed to environment for years, checking of OPS concrete under alkali-silicate reaction is a must. For motor bars, 200 ∗ 10 ∗ 10 mm bars are made, and for prism bars, 100 ∗ 100 ∗ 500 mm bars are made to examine the expansion of concrete under alkali-silicate reaction. As shown in Figure 8, samples are casted and demolded and tested in an expansion bar gauge to understand the reaction in the concrete.

Table 4 shows the expansion of coated OPS aggregate concrete under alkali-silicate reaction. This concrete made with coated OPS is immersed in NaoH solution for 28 days and 90 days to observe the reaction that happens in the concrete [27]. 90-day expansion of nanocoated OPS concrete is 0.04 to 0.03 mm which represents lower expansion rate in the concrete. This expansion of concrete is in ASTM limit; hence, this type of concrete and coatings is recommended to replace the conventional concrete with OPS lightweight concrete.

4. Conclusions

(i) OPS have higher pore size than the conventional aggregate. These pores are of size 10-15 micrometers

(ii) Concrete made with OPS shows lower mechanical behavior than the conventional concrete; this is due to the higher water absorption in OPS concrete

(iii) OPS are treated with nanosilane coating to fill the pores on the surface of the aggregate as well as to maintain the higher bonding between aggregate and cement paste

(iv) Interfacial transition zone shows fewer gaps between the coated OPS aggregate and the cement phase; this shows the bonding between the constituents of the concrete is higher than the nontreated OPS concrete

(v) Mechanical behavior of coated OPS shows 28 MPa compressive strength and 15 MPa in normal OPS concrete

(vi) EDX analysis shows mineralogical properties of coated OPS aggregate with elements in it, whereas not coated OPS shows amorphous peaks which represent crystal behavior

(vii) Alkali-silicate reaction for coated OPS shows much more protection than conventional concrete as the expansion of concrete is below the limit, and hence, coated OPS shows better performance than the conventional concrete

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Disclosure

The research was performed as part of the authors' employment in Mettu University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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