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Data Article

Physicochemical and mineralogical characterization datasets from oil drill cuttings in comparison with other cement types for cement partial-replacement in concrete

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A B S T R A C T

This article presents data on the physical/chemical and mineralogical characterizations of treated oil drill cuttings (ODC) in comparisons with other cement types, for suitability insight for partial-replacement of cement in concrete. The physical properties were compared for cement/cement fillers including Portland Cement (PC), Pulverized Fuel Ash (PFA), and Ground Granulated Blast-furnace Slag (GGBS). The particle size distribution of the ODC and the other cement/cementitious materials were also rendered to the extreme-value probability density models, with the Normal distribution employed as a reference, while the goodness-of-fit data-distribution compatibility was ascertained using Kolmogorov-Smirnov test-statistics. Characterized properties indicated treated ODC physicochemical and mineralogical properties compared well to the ranges exhibited by the other cement types, and requisite standards. The presented comparative results from the measured/analyzed physicochemical and mineralogical data are useful information for furthering research on the suitability of ODC, wastes from oil and gas explorations, as partial-replacement of cement in concrete.

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Specifications table

Subject area	Engineering, Materials Science and Engineering, Civil Engineering, Petroleum Engineering, Sustainable Environment Engineering, Physical Chemistry
Compounds	Bulk oxide mineral compounds
Data category	Physicochemical, mineralogical and statistically modeled data
Data acquisition format	Measured data of physical, chemical and mineralogical characterization with statistical data models of the particle size distribution
Data type	Raw data from analytical processes and equipment, analyzed
Procedure	Particle size distribution data was obtained by Laser diffraction technique using Mastersizer 2000 Particle Analyser (Malvern® Panalytical™), Bulk oxides composition analyses employ X-ray Fluorescence Spectrometer (XRF), Mineralogy composition of oil drill cutting was assessed using X-ray diffraction technique by the Hiltonbrooks X-ray Diffractometer
Data accessibility	A comprehensive dataset of physicochemical and mineralogical characterization of oil drill cuttings for comparison with other types of cement and assessing suitability for partial-replacement of cements in concrete is provided in this article

1. Rationale

The increasing global demand of energy, on which many utilities of socioeconomic well-being of modern society are dependent, necessitates continuous sourcing of energy resource from which the conventionally sourced energy usage remains paramount [1,2]. Mostly used for the conventionally sourced energy are still the fossil fuels due to the high density of continuous energy that can be derived from these sources of energy, stored over a long time within the confines of our planet [1]. Among the fossil fuel sources, petroleum, the rock oil, is extensively consumed on a large scale, globally, for both domestic and industrial applications. This ensures fossil fuel extraction from onshore and offshore reservoirs is a going concern of global venture as well as a day to day activity [3,4]. The concerns from this, however, are that exploration activities of petroleum from oil reservoir through drilling operations, lead to the generation of oil drill cuttings (ODC) as waste products [5–7].

When obtained from the point of crude oil exploration, ODC are mixed with the drilling mud, chemical compounds, and oil. In this heterogeneous form, it is a soil-like waste material that is highly hazardous to the environmental ecosystem if disposed to the environment without adequate treatment involving removal of environmental contaminants [5,6,8]. Thus, additional costs and energy are required for treating ODC materials, which grossly reduces the environmental hazardousness of the ODC materials in order to avert adverse environmental consequences that could rather ensue from disposal of untreated ODC wastes. Treatments methods usually employed for ODC includes stabilization-solidification/solidification process, bioremediation, thermal desorption method, as well as vitrification/devitrification techniques [5,7–16]. In contrasts, therefore, treated oil drill cuttings constitute stable materials, such as shale, quartz, sand, and limestone, which exhibited good physical and mechanical properties in the bulk material.

However, the needs for the expensive costs incurred, intensive energy utilized and considerable time consumed [11] in the treatment of oil drill cuttings not to be wasted generate interests among relevant stakeholders and researchers on ODC materials reusability [17,18]. More so, such reusability will essentially culminate in waste valorization, owing to the large quantity of oil drill cuttings that have to be subjected to waste management processing for averting disposal/discharge that are unsustainable to the environment [11,15,16]. Based on these reusability considerations, studies [15,17] have deliberated on the possibility of employing ODC material as a filler in bituminous mixture [17] or for drill cuttings-derived glass-ceramics for tiling heavy duty floors [15]. Despite these studies, other reported work, in the literature [18], has indicated needs for studies on the applicability of ODC in concrete block mixes for construction materials [18]. Therefore, this dataset article constitutes measured and statistically analyzed physical, chemical and mineralogical data. Presented datasets in this article could lend insights into, as well as find usefulness towards furthering research works, on the usability of oil drill cuttings that had undergone treatment as filler for partial-replacement of cement in concrete.

2. Procedure

Treated ODC for the study were obtained from licensed processors in the North Sea. These were milled and processed to remove heavy metals and hydrocarbon conforming to less than 1% content of hydrocarbon as limit requirement in BS EN 197 [19]. Also, via mechanical milling machine, the nominal size of the oil drill cuttings was ensured to be less than 0.063 mm, which is the required size for the ODC to fulfill the requirement need for use as filler in cement. Thermal desorption method at <600 °C temperature was used to reduce the hydrocarbon content to the <1% requirement by the BS EN 197. Heavy metal removal from the resulting ODC then followed the use of the adsorption process, due to the fact that the ODC is a silicate-based material.

Characterizations of the treated ODC samples were executed along with those of other cement/cement replacement materials including Portland Cement (PC) conforming to BS EN 197 [19], Pulverized Fuel Ash (PFA), and Ground Granulated Blast-furnace Slag (GGBS). These PFA and GGBS materials that were characterized in this work were procured commercially from Dundee, UK. The characterization techniques employed for the study include the physical, chemical and microstructural properties, and these were done for assessing the comparative properties for gaining insight into the possibilities of replacing the cement/cementitious materials with the ODC.

Table 1
Physical properties of oil drill cuttings and other cement/cementitious materials.

Property	Cement types			
	ODC	PC	GGBS	PFA
Apparent particle Density (g/cm^3)	2.76	3.14	2.81	2.27
Loss-on-ignition (%)	8.4	1.4	0.31	5.0
Specific surface area (m^2/kg)	712	251	409	535
Blaine Fineness (m^2/kg)	749	405	435	525

Table 2
Particle size distribution (% by volume) of oil drill cuttings and other cement/cementitious materials passing Sieve BS ISO 3310-2 [21].

Particle size range (μm)	Cement Types			
	ODC	PC	GGBS	PFA
600	100	100	100	100
500	99.90	100	100	99.98
250	98.75	100	100	99.67
125	97.34	100	100	98.17
106	96.72	100	100	99.68
90	95.78	99.79	99.94	94.56
75	94.21	98.24	99.29	91.47
63	92.08	95.58	97.48	87.89
53	89.36	91.72	94.71	83.91
45	86.28	86.95	91.09	79.87
38	82.67	81	86.37	75.52
10	51.48	28	39.38	37.68
4.4	31.73	9.53	20.15	17.91
1.5	9.24	2.5	6.61	6.7
0.4	0.09	0.17	0.16	0.22
0.3	0.00	0.00	0.00	0.00

Thus, characterized physical properties included apparent density measurements, using Archimedes principle, as well as particle size analysis, via the laser diffraction technique of the Mastersizer 2000 particle analyzer (Malvern® Panalytical™). For the determination of the particle size distribution of the ODC, PC, GGBS and PFA samples, the instrument reliance was on the water reactivity with the test samples. For this reason, water was used as means of a dispersing agent for the ODC, GGBS and PFA samples while propan-2-ol was employed as the dispersing agent for the PC sample. For these, small quantities of each material were added to the dispersed liquid in the glass vessel attached to the Hydro MU unit of the analyzer and this vessel was agitated and circulated continually for 30 seconds. The results were recorded and analyzed by requisite software that had been inbuilt into the analyzer system.

Chemical constituent characterizations were obtained through analyses of the X-ray Fluorescence (XRF) Spectrometer. These were done for the ODC, PC, GGBS and PFA samples and it involves the determination of elemental contents and bulk oxides composition analyses of the XRF methodology. Each of the samples of cement/cementitious materials was prepared in powder form, placed inside a 32 mm diameter mould and compacted under an initial load of 75 kN for 5 min. This choice of the initial load was for avoiding cracking and breaking the test-samples. Thus, after the initial 5 min, further compaction using 150 kN load for another 10 min was applied to the test-samples for XRF analyses. Compacted samples of the cement/cementitious materials were then placed inside the XRF machine that was attached to a computer desktop, which had been installed with the requisite software for record and analysis.

The mineralogical constituent characterization for the ODC was obtained from X-ray Diffractometer (XRD) analyses. This employed the Hiltonbrooks X-ray Diffractometer having monochromatic Cu Kα radiation source and curved graphite, single crystal chrometer (30 mA, 40 kV). The XRD equipment was used to determine the crystalline phases present in the cements. For doing this, powder samples were prepared with the addition of 5%, of the test sample, of corundum for identification of the crystalline components. The resulting sample from this was then compacted uniformly into aluminium window with glass slides before it was loaded into the XRD machine for the mineralogical analysis of the ODC.

3. Data, value, and validation

The experimentally measured data of physical properties of the ODC sample and the samples from other cement/cementitious materials, i.e. PC, GGBS and PFA, are as presented in Table 1 and in Table 2. In a similar manner, the mineralogical data, from XRF analyses, of the ODC and the other cement types for the study are presented in Table 3, while the results obtained from the XRD characterization of the ODC are presented in Table 4. In Table 1, the values of the ap-

Table 3
Bulk oxide and mineralogical characterization of the Cements (XRF analysis).

Base element	Elemental bulk oxide (% by weight)	Cements type			
		ODC	PFA	GGBS	PC
Ca	CaO	10.16	2.25	39.08	64.07
Si	SiO_2	37.00	24.58	37.03	20.15
Al	Al_2O_3	11.40	11.89	12.44	5.86
Fe	Fe_2O_3	4.31	7.8	0.57	2.27
Mg	MgO	1.947	0.721	6.767	2.243
Mn	MnO	0.208	0.063	0.517	0.045
Ti	TiO_2	0.598	0.815	0.681	0.274
K	K_2O	1.948	1.890	0.638	0.696
Na	Na_2O	1.156	0.582	0.489	0.369
P	P_2O_5	0.180	0.235	0.037	0.457
Cl	Cl	3.031	0.036	0.015	0.180
S	SO_3	4.048	0.647	1.073	2.583

Table 4
XRD mineralogical characterization of the treated ODC materials.

Mineralogical name	Chemical name	Chemical formula	Normalised composition %
Quartz	Silicon dioxide	SiO_2	16.1
Barite	Barium Sulfate	$BaSO_4$	14.9
Calcite	Calcium Carbonate	$CaCO_3$	8.8
Halite	Sodium Chloride	NaCl	5.8
Kaolinite	Kaolin clay	$Al_2SiO_5(OH)_4$	19.1
Muscovite	Muscovite	$KAl_2(ALSi_3O_{10})(Fe_3OH_2)$	3.5
Siderite	Iron Carbonate	$FeCO_3$	0.5
Corundum	Aluminium Oxide	Al_2O_3	0.0

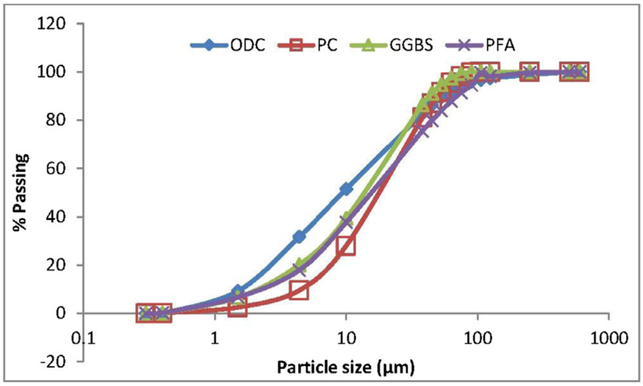

Fig. 1. Plots of particle size distributions of ODC and the other cement types for the study.

parent density (g/cm^3), loss-on-ignition (LOI, %), specific surface area (m^2/kg) and the Blaine fineness (m^2/kg) are presented for the tested materials. From this, it could be noted that the apparent particle density of 2.76 g/cm^3 for treated ODC in this report falls within the range of values indicated in previous studies [15,17,18] for this material. Thus, while the value of 2.76 g/cm^3 in this study just ranged beyond the 2.7 g/cm^3 upper value indicated for treated ODC in [18], it just compares well with the 2.75 g/cm^3 obtained for ODC subjected to vitrified treatment in [15]. Also, the apparent particle density of ODC in the present study falls within the range of 2.52–2.78 g/cm^3 obtained from treated tested ODC samples from the North Sea detailed in [18]. Additionally, just as that apparent density value in [15] was within the range of other glass-ceramics chosen for comparisons in that study, the 2.76 g/cm^3 apparent density falls within the range of the cement/cementitious materials tested for this data article report. The LOI for the ODC in this study at 8.4% is higher than LOI of the other cement types, but it is lower than the 11.63% LOI obtained for dried drill cuttings in [15]. The higher value of LOI exhibited by the ODC material can affect the compressive strength of concrete in which the ODC will be used for partially replacing cement, compared to the other types of cementitious materials, the GGBS and the PFA, of lower LOI values. However, the also higher 749 m^2/kg Blaine Fineness value of the ODC material, relative to the Blaine Fineness values of the other cement types, can lead to compressive strength improvement [20]. This higher Blaine Fineness can thus compensate for the compressive strength reduction that could result from the higher LOI of the ODC.

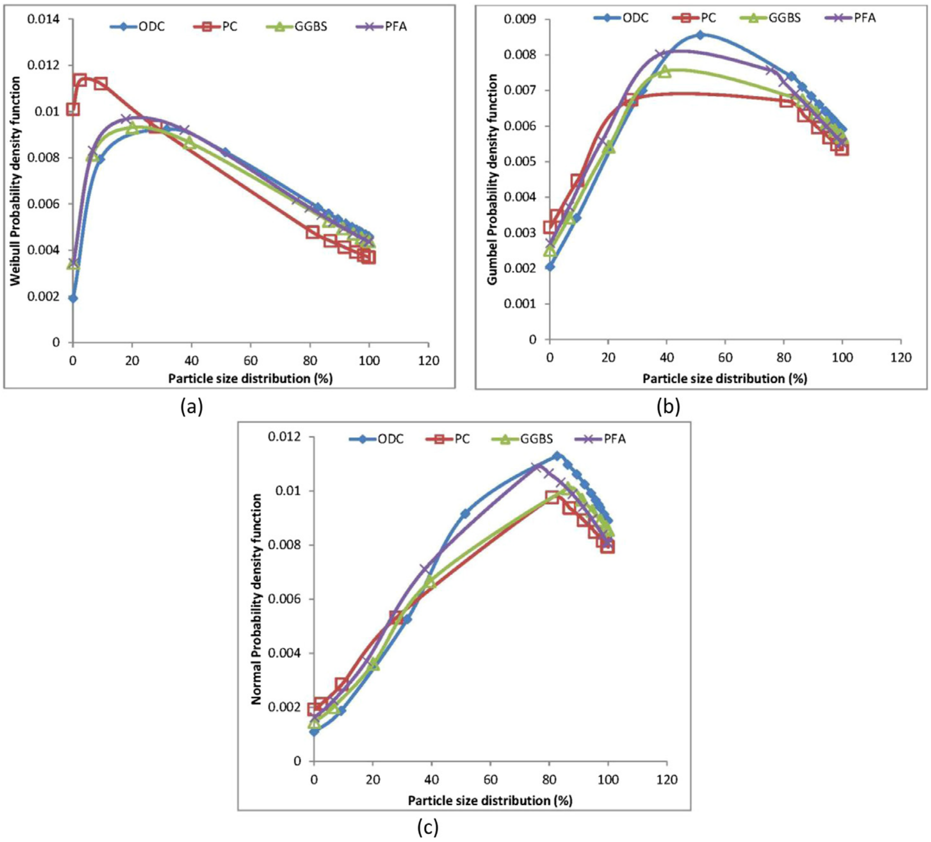

Fig. 2. Plots of probability density fittings of particle size distribution data from of ODC and the other cement types for the study (a) Weibull (b) Gumbel (c) Normal.

Particle size distribution of the ODC material, Table 1, portrayed values that patterned like the values from the PFA material for the range 75 μm ≤ particle size ≤ 600 μm for which both of these materials exhibited 89% < particle size distribution ≤100%. From the ≤ 63 μm sizes, the size distribution of the ODC tended toward those of the PC and GGBS materials, down to the 38 μm size where these three cementitious materials exhibited >80% particle size distributions. In contrast, at this 38 μm particle size, the size distribution of the PFA material has been reduced to 75.95%. Beyond this 38 μm particle size, on the particle size decreasing range, the particle size distribution for all the four cement types for this study rapidly reduces towards zero, as the particle sizes tend towards 0.3 μm. This is such that none of the cement types have particle size lower than 0.4 μm. The ODC materials also followed the other cement types in conforming to the BS EN 933 – 10 [22] specifications for fillers, by having greater than 70% of its particle sizes passing the 63 μm.

In a similar manner to what obtained from the data of physical properties, the mineralogical data of the ODC was within the range of the values gotten from the other cement types, as presented in Table 3. More especially, the ODC materials exhibited highest bulk oxide (mineralogical) constituent as SiO_2, for which it has 37.00% by weight, just as PC that also has 24.58% SiO2 of as the highest bulk oxide constituent. Unlike the ODC and PC materials, both GGBS and PFA have CaO as the highest mineralogical constituent, at 39.08% and 64.07% respectively. In spite of these, however, the SiO_2 constituent of 37.03% obtained from GGBS still compare well with the 37.00% from ODC, just as the SiO_2 of 20.15% from PFA also exhibited good comparison with the 24.58% from the PC. These mineralogical datasets from XRF analyses corroborate the datasets obtained from the further analyses of the ODC material via XRD characterization, in Table 4. In this table, XRD mineralogical data indicated silicate-based compounds such as Quatz (SiO_2), Kaolinite ($Al_2SiO_5(OH)_4$) and Muscovite ($KAl_2(ALSi_3O_{10})(Fe_3OH_2)$) with the respective constituents of 16.1%, 19.1%% and 3.5%. Additionally, both of the datasets from Table 3 and from Table 4 confirmed ODC materials as a silicate-based material, hence justifying the use of adsorption process for the removal of heavy metal from the ODC sample for the study.

Based on the foregone descriptions, the presented datasets in this article exemplify the value of the data as forms of information for furthering research on the performance criteria that could make ODC, a form of waste material, useful for partial cement replacement in concrete. Some of the values of these presented data include:

- Physicochemical properties of treated ODC are needed for assessment of the applicability of ODC waste materials from petroleum exploration for avoiding stringent policies against disposal of the materials in the environment [4,6,15,16,18];

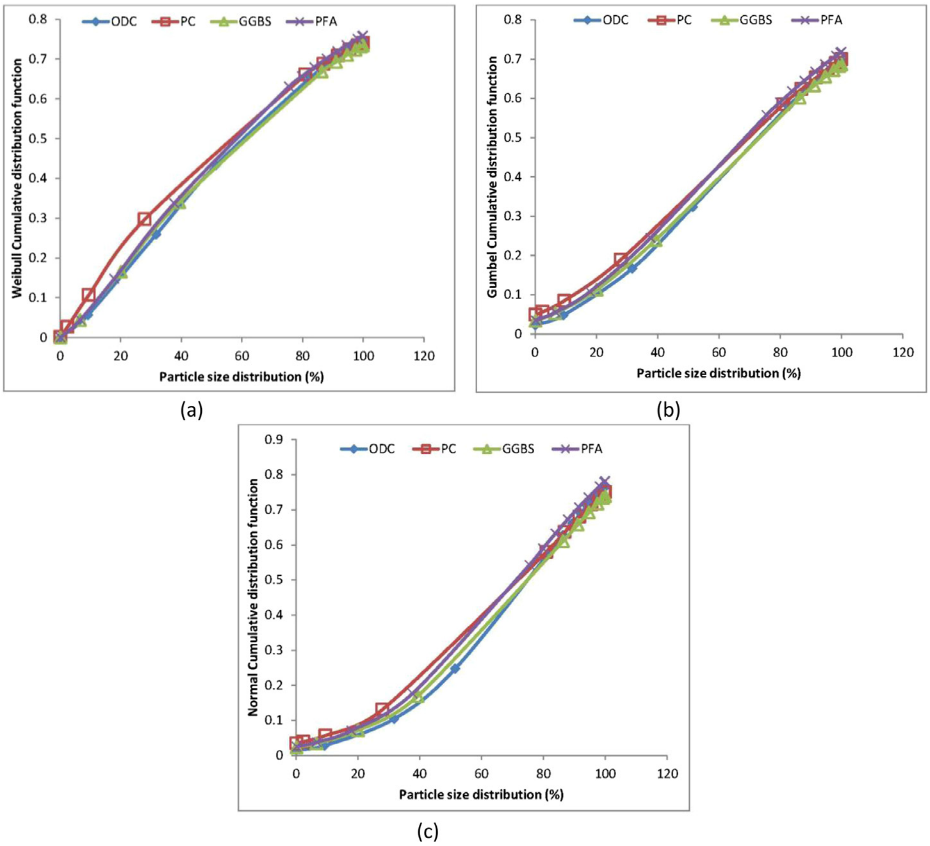

Fig. 3. Plots of cumulative distribution fittings of particle size distribution data from of ODC and the other cement types for the study (a) Weibull (b) Gumbel (c) Normal.

- Dataset of physical properties are needed for identifying materials that could be suitable for partial-replacement of cement in construction materials [17,18];
- Datasets of chemical and mineralogical properties are needed parameters for identifying suitable additive that will impact positively or otherwise to the properties of freshly cast concrete [18];
- Datasets of physicochemical and mineralogical properties are needed parameters for identifying suitable admixture that will impact positively or otherwise to the hardened properties of concrete [18];
- Datasets of chemical and mineralogical properties are also useful parameters for furthering research on the corrosion resistance of concrete material having ODC admixture [18].

The plots of particle size analyses of the cement types for the study are presented in Fig. 1. The plot shows that the treated ODC of this study exhibited particle size distribution that followed the *S*-curve grading distribution of the other types of cements considered in the study.

It is also worth noting that the *S*-curves of the raw data plots in Fig. 1 patterned after standard variates of cumulative distribution functions [23–25]. These motivate statistical validation of the independently and identically distributed (iid) random data of particle size distribution via rendering to the extreme value probability density models of the Weibull and Gumbel, while using the Normal distribution as a reference model [26–29]. The value of these statistical analyses, therefore, rather than being on the study of measurements of central tendency or of dispersion for describing the iid datasets, is on the leveraging on the parameters from the statistical distribution models for validating the patterning of the ODC particle size distribution like the other cement types in the study. This particle size distribution constitutes the criteria for suitability for use as partial-replacement of cements in concrete as per the specification for fillers in BS EN 933-10 [22].

Fig. 2, therefore, presents plots of the probability density fittings of the particle distribution data of the cement types by the Weibull, Gumbel and Normal models [30–35] while the plots of the cumulative distribution fittings by these plots are presented in Fig. 3. Thus, based on results from these statistical models, Fig. 4 presents plots of the values of the location, shape and scale parameters of the Weibull, Gumbel and Normal probability density analyses of the particle size distributions obtained from the ODC and other types of cements for the study. Also, Fig. 5 presents the plots of *p*-values from the Kolmogorov-Smirnov goodness-of-fit test-statistics [32–33,36–39] and the linear plot of $\alpha = 0.05$ level of significance, for

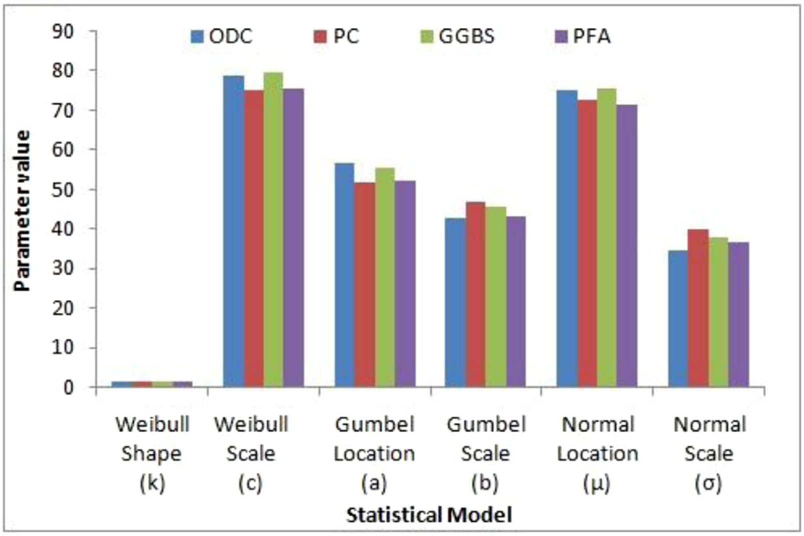

Fig. 4. Plots of the statistical distrituion parameters from the particle size analyses of ODC and the other cement types for the study.

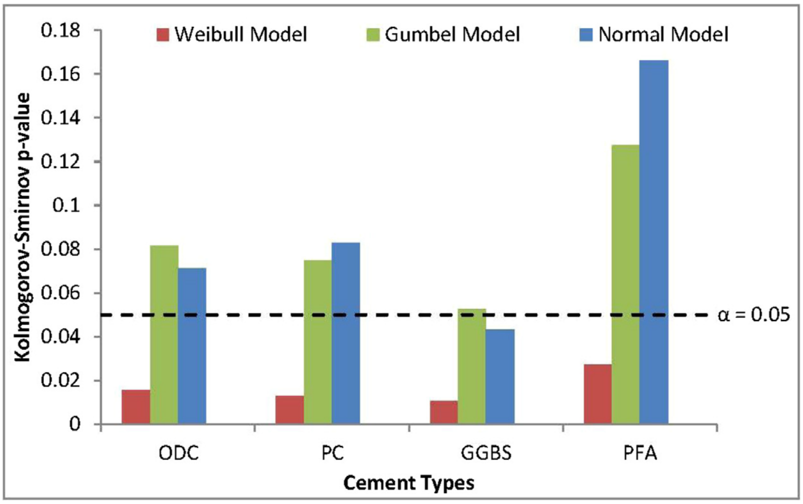

Fig. 5. Plots of the Kolmogorov-Smirnov *p*-values from the statistical distribution analyses of particle sizes of ODC and the other cement types for the study.

ascertaining compatibility of the statistical probability density fitting models to the particle size distribution data directly from the figure.

Fig. 5 shows that the particle size distribution data did not come from the Weibull distribution but that the datasets distributed like the Gumbel and the Normal probability density functions, at $\alpha = 0.05$ level of significance, for ODC and the other cement types studied. These findings are corroborated by the curves of the cumulative distribution function curves wherein the plots of the Gumbel and the Normal models, Fig. 3(b) and Fig. 3(c), are closer to the *S*-shape of the particle size distribution curves, Fig. 1, than the curves from the Weibull model, Fig. 3(a). Further supporting the non-scattering of the particle size distribution like the Weibull probability density model are the relatively low values of the Weibull shape parameters, *k*, for the studied cement types, as plotted in Fig. 4. These Weibull shape parameter values, for the cement types, were in the range $1 < k < 1.4$, which bare implications that the particle size distribution exhibited large scatter when fitted to the descriptive statistics of the Weibull probability density function. Also, in an exception to the other cement types, the particle size distribution dataset from the GGBS material did not scatter like the Normal probability density model, as per the results from the Kolmogorov-Smirnov goodness-of-fit test-statistics whereby *p*-value <0.05. This further portrayed the importance of employing distribution-free/non-parametric test-statistics such as the Kolmogorov-Smirnov goodness-of-fit for ascertaining compatibility of the scatter of data to descriptive statistics, beyond the estimations of the statistical parameters. Therefore, the statistical distribution modeling of the particle size distribution indicated that the scale and location parameters by the Gumbel distribution could be used for characterizing the *S*-curve of the particle size distribution of the studied cement types. Also, the location and shape parameters of the Normal distribution could also be used for characterizing the *S*-curve of the particle size distribution of only the ODC, PC and PFA materials, but not that of the GGBS material.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cdc.2019.100176.

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