Novelty Journals

ISSN 2394-7357

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 1, pp: (6-15), Month: January - April 2025, Available at: www.noveltyjournals.com

Compressive Strength and Microstructural Properties of Bituminous Sand Concrete

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DOI: https://doi.org/10.5281/zenodo.14998758

Published Date: 10-March-2025

Abstract: **The compressive strength and microstructural characteristics of bituminous sand-based concrete are the main subjects of this investigation. Open excavation was used to obtain bituminous sand, which was then crushed with a scoop to sand sizes. Bituminous sand and river sand, which served as a control, were combined with regular Portland cement. Cement, aggregates, water content, and the ratio of water to cement did not change. The fresh concrete was subjected to tests for slump and compacting factor. The fresh property test, compressive strength test and microstructural analysis were done for normal strength concrete as well as bituminous sand concrete (BSC). The fresh property of concrete was evaluated using slump test and compacting factor test. The compressive strength was done after curing the samples for 7, 14, 21, 28, 56, 90 and 150 days respectively. Microstructural analysis was done via scanning electron microscope and Energy dispersive X-ray spectroscopy (SEM-EDS) for all concrete mixes. From the investigation, BSC concrete is more workable compared to the control. The compressive strength of the samples increased with increase in curing age though at a different rate with the control concrete gaining the highest strength. The BSC attained grade C15 status at 28 days of curing. SEM micrograph for the BSC showed a crystalline-like irregular shaped structure and the refined patterns and voids were more noticed compared to the control. From the EDS, the control concrete gave high silica to calcium, S/Ca ratio of 1342.2 while the BSC had S/Ca ratio of 46. Thus, this could be responsible for the low strength of the BSC at 28 days compared to the control at same curing age. This study has revealed that BSC is an excellent choice for developing unreinforced foundations for houses, paving, residential flooring and freestanding retaining walls.**

Keywords: **Bituminous sand, Bituminous sand concrete, Compacting factor, Compressive strength, Microstructural analysis.**

1. INTRODUCTION

Building development has increased as a result of the quickening pace of globalization and population growth, which has raised demand for building materials. Concrete is the most excellent construction material from human history [1, 2] and according to [3], aggregates are the main constituents in concrete and contribute greatly to strength development. One of the primary ingredients utilized as a fine aggregate in the manufacturing of concrete is river sand. The overexploitation of river sand due to an increase in the demand for building materials has had negative effects, including lowering the water table, increasing the depth of the riverbed, and introducing saline into the river. Furthermore, government agencies' restrictions on sand extraction have raised sand prices, thus impacting the stability of the building sector. [4]. Finding a substitute for river sand has therefore become essential. One substitute material is bituminous sand which is made up of sand, heavy oil, and clay that are high in water and minerals [5]. The heavy oil present in this sand is referred to as bitumen, a sticky, viscous black substance.

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[6] reported that the world's third largest confirmed or developed crude oil reserve is found in bituminous sands, which cover an area of 142,000 square kilometres (km^2). Also, [6] observed that bituminous sands are found in several countries around the world, especially countries in South America like Venezuela, Cuba, Brazil, etc. Bituminous sand deposits are found throughout the United States, primarily in Utah, Kentucky, Kansas, Missouri, California, and New Mexico. But according to [7, 8, 9], Athabasca, near Alberta Canada, is home to the largest known bituminous sand deposit. The occurrence of the Athabasca bituminous sand is found in the McMurray formation. The formation is located in a region of unconformity surrounding devonian carbonate rocks that exhibit surface denudation in the lower Cretaceous. The sand is typically unconsolidated, with grain sizes ranging from fine to coarse quartz sand and thickness variations. The sand has the following properties: weight percentage between 10 and 18 percent, net per zones, 20 to 40 meters, and porosity, 30 to 40 percent.

The Dahomey basin on the African continent has some sizable quantities of oil sands. A large portion of the Gulf of Guinea's continental edge is covered by the Dahomey basin. It stretches from the Okitipupa ridge in Nigeria in the east to the Volta delta in Ghana in the west. It is a marginal pull-part basin, also known as a marginal sag basin, that formed during the Mesozoic era when the continental margin foundered, and the African and South American lithospheric plates split apart. [10-14].

Bituminous sands are abundant in Nigeria [15–16]. With a belt of roughly 120000 km stretching south-easterly direction from the Ijebu-Ode (60 50' N and 40 54' E) ridge/western feather edge of the tertiary Niger Delta to as far east of Okitipupa (60 30' N and 40 50' E) in Ondo state [19], the bituminous sand deposit in southwestern Nigeria is one of the notable deposits, and is thought to be among the largest in the world [17–18].

According to [20], who looked into how bitumen and diesel oil affected the concrete's compressive strength. In making his test concrete, he used sea sand that had been tainted by diesel oil and cut-back bitumen separately. Regardless of the age of the concrete, he found that the higher the percentages of bitumen and diesel oil in the fine aggregate, the lower the final concrete strength. When [21] examined how utilizing sand tainted with petroleum products affected the mechanical qualities of concrete, they found that the concrete's compressive strength, tensile strength, and bending strength (modulus of rupture) all declined in comparison to the reference concrete that was free of oil pollution. [22] discovered that the cohesiveness of concrete composed of fine sand tainted with light crude oil rose dramatically up to 1% of oil contamination before declining as the crude oil percentage rose.

Authors in [23] found that the presence of crude oil in concrete causes segregation and prevents the creation of bonds between the elements that make up the concrete. Thus, the addition of crude oil to concrete caused differences in the concrete's workability. The workability increases with the proportion of crude oil in the fine aggregate. Authors in [24] also studied the effect of kerosene imparted sand on the compressive strength of concrete in different exposure conditions and found out that a reduction of up to 27% in the concrete compressive strength occurred in 2% kerosene contaminated samples in all exposure conditions studied. In their analysis of how crude oil affected concrete's compressive strength, [25] found that 2.5 to 25% crude oil contamination reduced the material's compressive strength by 18 to 90%. [26] came to the conclusion that adding mineral oil to concrete makes it more compressible, which lowers the concrete's moduli of elasticity. While studying the effect of crude oil spill on the compressive strength of concrete materials [27], discovered that ordinary Portland cement concrete is susceptible to different aggressiveness of the solutions of crude oil concentrations as they led to low rates of strength development of concrete specimens.

The behaviour of concrete exposed to petroleum products has been extensively studied, but the characteristics of concrete made with bituminous sand have received less attention. Therefore, the purpose of this study is to examine the microstructural characteristics and compressive strength of bituminous sand concrete (BSC). Investigations were conducted into the characteristics of both fresh and hardened concrete. An empirical model was created using spreadsheet regression analysis to forecast the values of a dependent response variable in relation to other independent variables.

2. MATERIALS AND METHODS

2.1. Agbabu, located in the Odigbo local government area of Ondo state, Nigeria, provided the bituminous sand used in this study. The geographic grids of latitudes 60 35' 16.3"N and 60 37' 13.9"N and longitudes 40 49' 29.0"E and 40 50' 20.7"E contain Agbabu. Ilubinrin village borders Agbabu to the north, Ojumode village borders it to the south, Sheba village

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borders it to the east, and Lobuko village borders it to the west. Using a pick and a shovel, the bituminous sand was removed from the outcrop. The river sand used as the control for this study was high-quality, white, crisp sand from Otamiri river in Owerri, Nigeria. It was free of organic elements and trash. The bituminous sand sample that was collected was in a solid compact form. With the help of a scoop, the sample was crushed into sand-like pieces because it was challenging to work with in this condition. The coarse aggregate was crushed limestone aggregate (Ajali formation) maximum size 20mm obtained from Jingzang quarry km 40 Enugu – Abakaliki highway Okpoto, Ebonyi State, Nigeria.

The physical test carried out on the materials are as shown in table 2. They include the physical appearance of the aggregates, bitumen content of the bituminous sand, sieve analysis, specific gravity, natural moisture content, water absorption, bulk density tests and the Coefficient of curvature (gradation), C_c and uniformity coefficient C_u for fine aggregates were calculated using the formulae shown below:

$$C_C = \frac{(D_{30})^2}{D_{60} \, x \, D_{10}} \quad (1)$$

$$C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

A 42.5R ordinary Portland cement Dangote brand conforming to [28] and supplied by a retailer in Owerri, Imo state Nigeria was used as the cementitious material in this study. Samples were prepared with free water-cement ratio of 0.6 at a target strength of 25N/mm^2.

2.2 Batching and Mixing of concrete

In compliance with the concrete mix ratio of 1:2.2:3.3, the batching was done by weight. The cement was then evenly distributed over the mixture of crushed stone and sand after the coarse and fine aggregates had been combined and spread out on the laboratory's firm, clean floor. The materials were shoveled repeatedly from one end to another and cut with shovel until the mix appeared uniform. After that, water was injected gradually to prevent cement and water from escaping on their own. After that, the mixing process was repeated as for the dry stage until the mixture's color and consistency seemed consistent.

2.3 Tests on Fresh concrete

2.3.1 Slump test

Using Abram's slump cone apparatus, the slump test was conducted. The purpose of this experiment was to gauge the filling ability of concrete. The control concrete and bituminous sand concrete (BSC) were both used in the test. Fresh concrete was poured into the apparatus in three layers, each containing 25 blows. To allow for concrete distortion on a flat metal plate, the cone was vertically removed. It was measured to determine the new height. The height difference between the cone and the concrete cone upon removal was calculated. See figure 1 and table 3.

2.3.2 Compacting factor test

This test measures the degree of compaction resulting from the application of a standard amount of work [29, 30]. The apparatus used was obtained from the structural Engineering laboratory of the department of Civil Engineering, Federal University of Technology Owerri (FUTO) Imo state Nigeria. It basically comprises of one cylinder and two hoppers, each shaped like a cone's frustum. The mixed concrete was carefully poured into the hopper to fill it about halfway, but no consolidation was used. The top flap was then released, allowing it to drop into the second hopper. The second flap opened as the cylinder was uncovered after being placed in the second hopper. Concrete spills out of the cylinder as it fills. Only gravity causes consolidation.

Two trowels working inward took off the extra concrete, and the whole cylinder was then taken out and weighed. The net weight was obtained. After that, the cylinder was emptied and refilled in layers that were about 50 mm deep. It was then fully filled and either strongly rammed or, if it was not workable, vibrated, the goal was to eliminate any air spaces after weighing. The second net weight was determined. The ratio of the actual density measured during the test to the density of fully compacted concrete was used to calculate the compacting factor as given in equation 3.

The compacting factor, CF = $\frac{1st \ net \ weight}{2nd \ net \ weight}$ (3)

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This is a fraction and the higher the value the more workable the concrete; and the lower, the less workable the concrete. See figure 2 and table 3.

Fig.1.Slump test

Fig. 2. Compacting factor test

2.4 Preparation of specimens for strength test

The specimens were prepared firstly by using a brush to grease the inside of the 150-mm x 150-mm x 150-mm molds to facilitate simple de-molding. Secondly, using a mason's trowel, the properly mixed concrete was poured into the cubical molds in three layers. The first, second, and third layers were evenly distributed across the mold's cross section and giving a compaction of 25 blows with a rammer at its own weight in accordance with [31]. The top of each mold was smoothened and leveled, and the outside surfaces cleaned. A total of 42 cubes (21 control and 21 bituminous sand samples) were made for this study. A day later, the firm concrete was removed from the mold and moved to the water-filled curing tank until tested.

2.5 Compressive Strength test

One of concrete's most distinctive qualities appears to be its high compressibility. The concrete performance test has historically been used to determine whether a concrete cube measuring 150 x 150 x 150 mm can achieve particular compressive strengths after 28 days. For the purpose of this study, compressive strengths of the bituminous sand concrete and the hardened control concrete were measured at 7, 14, 21, 28, 56, 90, and 150 days after curing using a compressive strength testing machine that met [32]'s requirements. The test was carried out on duplicate samples of concrete cubes that were 150 mm by 150 mm by 150 mm at each curing age in accordance with [33]. 42 samples in total were crushed, as table 1 demonstrates.

Table 1. Number of samples crushed

Sample type	Curing ages	Replicates	Number of samples
Control-River sand	7, 14, 21, 28, 56, 90, 150	3	21
Bituminous sand	7, 14, 21, 28, 56, 90, 150	3	21
Total			42

2.6 Microstructural analysis of specimens

After 28 days of hydration, the microstructural characteristics and elemental compositions of the control and bituminous sand concrete (BSC) were investigated using a Scanning Electron Microscope and Energy Dispersive X-ray Spectroscopy

(SEM-EDS) via Model JEOL-JSM 7600F machine. These tests were conducted at the core laboratory of Covenant University's Centre for Research, Innovation, and Discoveries (CUCRID). Magnification, accelerated voltage, and pressure were all set at 70Pa, 15KV, and 9000X, respectively, for the SEM examination, and the working distance was between 11.0 and 12.0 mm. A flat (general) scan was used for the EDS analysis. The samples were securely held in position using double-stick carbon tape and carbon coating on an aluminum holder stub.

3. RESULTS AND DISCUSSION

3.1. Physical properties

The results of the physical properties tests of the river sand, bituminous sand and granite used for the study are shown in table 2.

Table 2. Physical properties of materials

Property type	Bituminous sand	River sand	Granite
Physical appearance	Dark-brown	White	Light-colored
Bitumen content (%)	8.8	-	-
Specific gravity	2.60	2.64	2.70
Moisture content (%)	0.60	0.72	0.08
Water absorption (%)	0.70	0.91	0.74
Bulk density (Kg/m^3)	1717	1780	1677
Gradation coefficient, C_c	0.80	0.73	-
Coefficient of uniformity, C_u	2.20	2.50	-
Fineness modulus	3.44	3.79	-

3.2. Fresh properties

Table 3 displays the results of the compacting factor and slump tests. The table shows that, in comparison to the control, the bituminous sand concrete (BSC) had a higher slump and compacting factor value. The presence of bitumen in the bituminous sand concrete (BSC) improved the rheological behavior of the concrete thus making the concrete more workable. Additionally, it is reasonable to believe that bitumen disrupted the cement-water binding interactions, preventing or postponing the cement particles' full hydration [34].

Table 3. Fresh properties of samples

Sample	Slump (mm)	Degree of workability	Compacting factor	Remark
control	30	Low	0.46	Very low
BSC	55	Medium	0.49	Very low

3.3. Compressive strength

Figure 3 displays the average compressive strength of the concrete samples (control and bituminous sand samples). The bituminous sand concrete's (BSC) compressive strength was significantly impacted. All of the samples' compressive strengths rose over time, albeit at varying rates. After seven days of curing, the control concrete's compressive strength was 15.17N/mm2, or 60% of its specified strength. The control sample continuously maintained the highest compressive strength values over time, while the bituminous sand sample's values increased with curing age but did not outperform the control at the different testing ages. The fact that bituminous sand concrete (BSC) becomes stronger over time implies that as the hydration process progresses, more calcium silicate hydrate is produced, increasing the strength of the concrete. At 28 days, the bituminous sand and control concretes' respective compressive strengths were 15.02N/mm^2 and 24.70N/mm^2, or 60.08% and 98.80% of the design concrete strength, respectively. This indicates that by 28 days, the control concrete's strength has increased by 38.72% compared to the bituminous sand concrete. The control concrete's strength at 150 days of curing was 26.93N/mm^2, while the BSC's was 15.35N/mm^2. In their study, [35] also reported a similar decrease in the strength of concrete containing hydrocarbon when compared to the control.

At the ages of 56, 90 and 150 the control concrete gained an additional 4.24, 4.72 and 8.92% compressive strength respectively over the 28-day compressive strength while at the ages of 56, 90 and 150 the bituminous sand concrete gained an additional 0.8, 1.2 and 1.32% respectively over the 28-day compressive strength. The bitumen in the bituminous sand, which is a component of the microstructure of the concrete matrix, may have caused the gel to dilate, the cohesive forces in the paste to weaken, and the internal hydraulic pressure to rise as a result of the bitumen's absorption, all of which could have contributed to the low strength development of the concrete cubes.

Though bituminous sand concrete at 28 days of curing gained a strength of 15.02N/mm^2 which is less than the design strength of 25N/mm2, this strength is among the standard regular strength grades of concrete that is C10, C15, C20 and C25, which is an excellent choice for developing unreinforced foundations for houses, paving, residential flooring, and freestanding retaining walls.

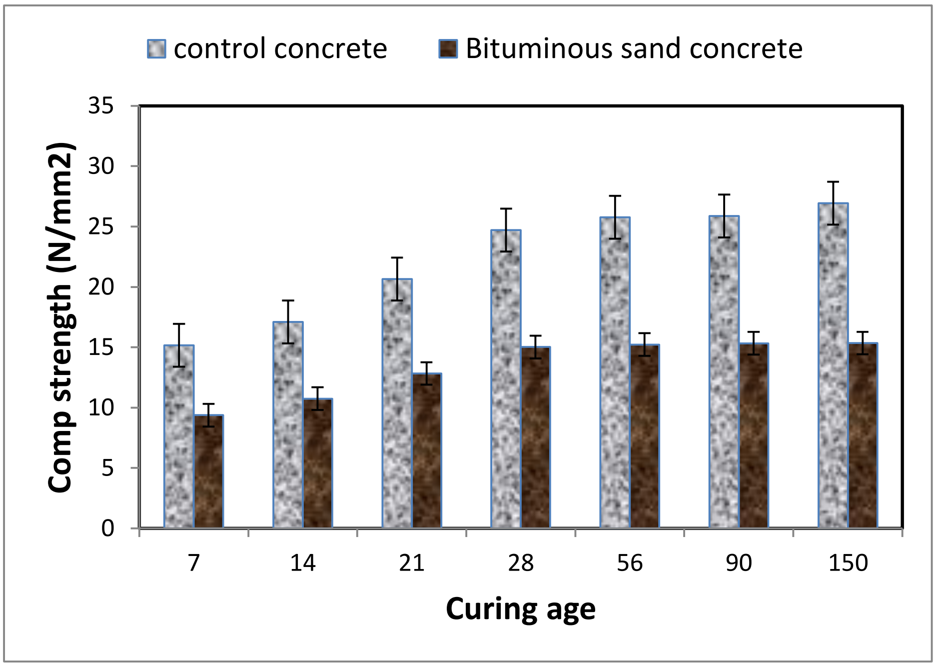

Figure 3. Average Compressive Strength of Concrete (Control and Bituminous sand sample)

3.4. Microstructural Characteristics of BSC

Figures 4 and 5 show the findings of the microstructural analysis and elemental compositions of the control and BSC samples using SEM-EDS after 28 days of curing. As indicated in figure 4a, the SEM micrograph for the control concrete revealed an amorphous-like shaped structure with better interface condition and uniform matrix. While the SEM micrograph for the BSC figure 5b showed a crystalline-like irregular shaped structure with a less better interface condition indicating a less adequate compact and uniform matrix. In the SEM micrograph of control figure 4a, the refined patterns and voids were rarely noticed compared to the micrograph of the BSC figure 5a. The bitumen in the BSC may not have allowed the formation of uniform matrix which could be responsible for the low strength of the BSC. Thus, these could have led to the higher strength gain by the control concrete.

The Energy Dispersive X-ray Spectroscopy (EDS) examination of the concrete samples, which determined the primary chemical elements contained in each sample, is displayed in Figures 4b and 5b. Every sample had calcium-silicate-hydrate (C-S-H), according to the EDS analysis, and important ingredients included silicon Si, oxygen O, aluminum Al, calcium Ca, and iron Fe. The silicon over calcium (S/Ca) ratio is usually used to evaluate the amount of C-S-H. High S/Ca ratio indicates more C-S-H content. The control concrete gave a higher S/Ca ratio of 1342.2 while the BSC has a S/Ca ratio of 46. Thus, this could be responsible for the low strength of the BSC at 28 compared to the control at same curing age.

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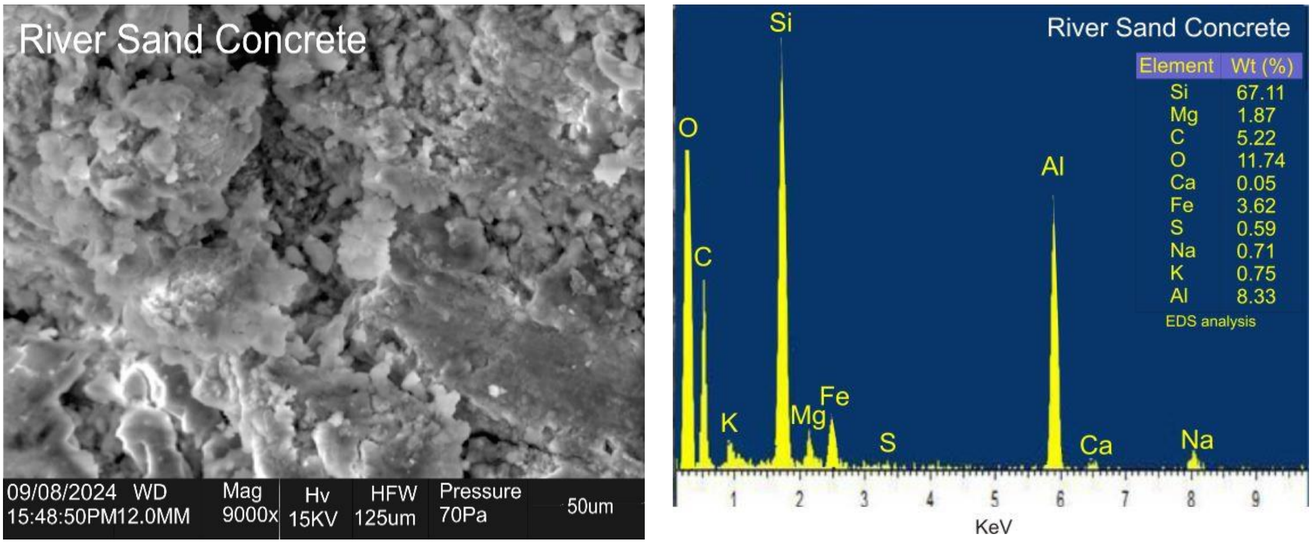

Figure 4 a & b: SEM Micrograph and EDS for River sand (Control) Concrete

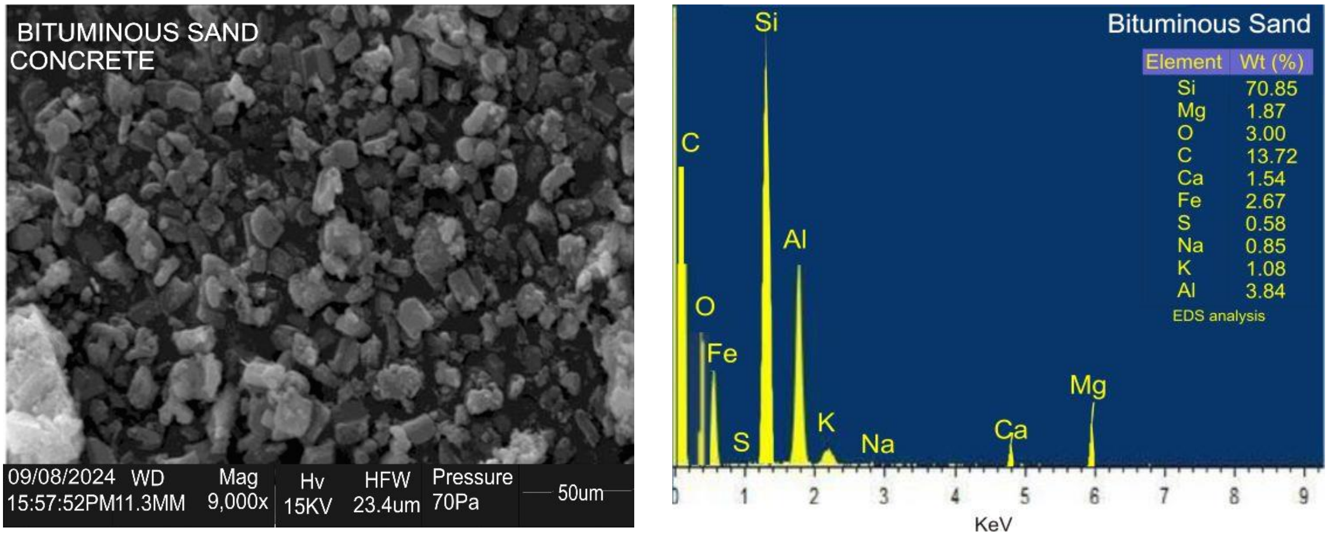

Figure 5 a & b: SEM Micrograph and EDS for Bituminous sand Concrete (BSC)

3.5. Model

The model developed for the BSC is shown in Eq.4. Y represents Compressive strength, X_1 represents curing age in days and X_2 represents dry density in Kg/m^3.

$$Y = -98.78 - 0.00092X_1 + 0.05X_2 \quad (4)$$

According to the results of the t-test, the alternative hypothesis is rejected, and the null hypothesis is accepted. In other words, at a 95% accuracy level, there is no discernible difference between the model-predicted concrete cube compressive strength findings and the laboratory data. As a result, the developed model is sufficient.

4. CONCLUSIONS

The compressive strength and microstructural characteristics of bituminous sand concrete (BSC) were examined in this work. In place of river sand, bituminous sand was employed as a fine aggregate. The materials were examined using SEM-EDS. Thus, the following deductions are made in light of the experimental and statistical findings:

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- There was an increase in slump and compacting factor of the BSC compared to the control.
- The BSC attained a compressive strength of approximately 15N/mm^2 at 28 days of curing.
- The C15 grade of BSC at 28 days makes it an excellent choice for developing unreinforced foundations for houses, paving, residential flooring and freestanding retaining walls.
- The microstructural examinations revealed the less amorphous and irregular shaped structure of BSC with a low silica to calcium ratio of 46
- The model developed with a good coefficient of determination was tested and found to be adequate.

Declaration of competing interest

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

Data availability

The article contains the original contributions made during the study; additional questions can be forwarded to the corresponding author.

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