ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 8, Issue 3, 284-292

Mechanical and Microstructural Performance of Concrete Incorporating Expanded Polystyrene as Partial Coarse Aggregate Replacement

Gideon Olukunle BAMIGBOYE[1], Joseph UNO[2], Ben Uchechukwu NGENE[3], Adebiyi Idowu OGUNDIPE[4], Kayode Joshua JOLAYEMI[1]

[1]*Department of Civil Engineering, Abiola Ajimobi Technical University, Ibadan, Oyo State, Nigeria*
gideon.bamigboye@tech-u.edu.ng/kayode.jolayemi@tech-u.edu.ng

[2]*Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria*
joseph.uno@stu.cu.edu.ng

[3]*Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, Nigeria*
ngene.ben@mouau.edu.ng

[4]*Department of Agricultural Engineering, Abiola Ajimobi Technical University, Ibadan, Oyo State, Nigeria*
adebiyi.ogundipe@tech-u.edu.ng

Corresponding Author: gideon.bamigboye@tech-u.edu.ng, +2348037738986
Received: 30/09/2025
Revised: 25/11/2025
Accepted: 02/12/2025
Available online: 04/12/2025

Abstract: *The increasing demand for lightweight and sustainable construction materials has led to the search for alternative aggregates in the production of concrete. This current study investigates the performance assessment of concrete strength with expanded polystyrene (EPS) as a partial coarse aggregate replacement. Concrete mixes were prepared with 5, 10, 15, 20, 25, and 30 varying percentage replacement of granite with EPS. Fresh and hardened properties were assessed through the slump, compressive, split tensile, and flexural tests at both early and late ages. Microstructural characterization was conducted using Scanning Electron Microscopy (SEM) and EDX to evaluate the interfacial transition zone (ITZ) and pore distribution. The results obtained showed that the addition of EPS at varying percentages produced a lightweight concrete usable for non-structural and some structural applications. An inverse relationship was observed between strength performance and EPS content, with higher replacement levels resulting in reduced strength. The optimal strength level was achieved at 5% EPS replacement. SEM and EDX analysis revealed weaker bonding in the ITZ at higher EPS contents, contributing to a reduction in strength, but also demonstrated improved energy absorption and ductility. It was concluded that EPS can be used in lightweight concrete production while promoting waste recycling and sustainable construction practices.*

Keywords: *Waste Management, Expanded Polystyrene, Coarse Aggregate, Concrete, Sustainable Materials*

1. INTRODUCTION

Concrete remains the most widely used construction material globally due to its durability, versatility, and cost-effectiveness. Lightweight concrete has been in use in the building industry for over two thousand years, with its use dating back to the Roman Empire when burned lime, Grecian and Italian pumice were used in its manufacture [1, 2]. Since Ancient Rome, various components have been utilized in the manufacture of lightweight concrete, with a few, like volcanic dust, fly ash, and tuff, having shown to have more desirable features than the Roman materials [2]. Until the 20th century, most of such improvements were with the strength of the cementing material rather than the aggregate [3].

Lightweight concrete is widely described as concrete that weighs substantially lower than normal-weight concrete, with densities ranging from 1440-1840 kg/m^3 [4]. Lightweight concrete can be classified into structural and non-structural concrete according to the type of application. The applications of light-weight structural concrete have been on the rise, particularly in the design and development of multi-storied structures, offshore structures, and long-span bridges. Its properties of light weight, high strength, and durability suit these structures as they result in a significant benefit in terms of decreasing the size of structural elements such as foundation, columns, and beams [5]. Lightweight concrete comes in two forms: light-weight aggregate concrete, or foamed concrete, otherwise known as autoclaved aerated concrete (AAC). The expression “Light-weight Aggregate” refers to a group of special-purpose aggregates with relative densities considerably lower than conventional sand and granite typically used in concrete. These aggregates span from incredibly light materials used for insulative and non-structural concrete to expanded clays, shales, and other artificial materials such as Expanded polystyrene beads (EPS) used for structural concrete, given that the light-weight nature of these aggregates is attributed to the entrapped air within them. Thus, if there is more entrapped air per every one particle, then the mass of the aggregate is bound to be lower, but conversely, the lower the strength such material will possess [3].

Expanded polystyrene (EPS), also known as Styrofoam, is made from blown polystyrene beads. Polystyrene is a petroleum-based plastic produced by linking styrene monomers [6]. It is a lightweight material, consisting of 95% air, which contributes to its excellent insulation properties. Styrofoam is considered unsinkable and can maintain its shape. EPS, a lightweight, non-biodegradable plastic widely used in packaging and insulation, presents a dual opportunity: its disposal poses environmental challenges because EPS waste occupies large volumes in landfills and resists natural degradation. The use of EPS offers low density, cheap and rapid manufacturing, ease of handling, and chemical inertness. It also functions as a common insulation material in construction. The properties that make EPS effective for packaging also make it difficult to decompose or recycle properly, taking approximately 500 years to naturally decompose [6]. Global plastic production increased from 1.36 million tonnes in the early 1950s to 271 million tonnes in 2013, and it is expected to continue rising [7]. Polystyrene products account for 7.1% of this, most of which end up in landfills [8]. Recycling EPS into concrete not only offers a sustainable disposal method but also helps develop lightweight concrete with better thermal insulation and lower dead loads, which is especially beneficial for high-rise structures, partition walls, and other applications where reducing self-weight is essential.

More so, the mining of natural resources for construction causes different levels of harm to the environment and its inhabitants, including the destruction of vegetation and ecosystems, contamination of ground and surface water, and respiratory problems from quarry dust [9, 10, 11]. Worse still, the frequent change in trends and human lifestyle has caused buildings to now have shorter life spans with a constant need for renovations and remodelling, expending more of the depleting material natural reserves. Thus, it is prudent to seek out sustainable and environmentally friendly substitutes for construction. The application of recycled waste in construction will most definitely improve public interest in waste recycling and serve as a prudent waste management method in countries all over the world.

In conducting an experiment on the partial replacement of coarse aggregate using polystyrene beads [12] found that the concrete workability increased with increasing polystyrene replacement. Despite the numerous research works done on the use of EPS in concrete, topics such as strength and microstructural assessment of the use of EPS in reinforced concrete have seldom been explored. Hence, this study aims to assess the strength (compressive, split, and flexural) and microstructural characteristics of mass and reinforced concrete produced using expanded polystyrene (EPS) as partial coarse aggregate replacement. By integrating compressive, tensile, and flexural strength results with SEM/EDX investigations of the EPS–paste ITZ and pore structure, the research provides new mechanistic insights and quantitative thresholds for EPS incorporation. The study fills a significant gap in understanding how EPS modifies ITZ morphology, pore distribution, and hydration chemistry, and establishes clear structure–property relationships. These tests are crucial for permitting structural applications. By doing so, it contributes to the broader discourse on sustainable construction practices, resource efficiency, and innovative waste management strategies.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study are sharp sand, ½ inch granite, Styrofoam, Ordinary Portland Cement (42.5N) (OPC) and potable water, and Conplast SP430 Plasticizer. The sharp sand, granite, and OPC, as shown in Figures 1-2, were obtained commercially from River Ogun, Igbo-Ora, and Ota, Ogun State, Nigeria, while the Styrofoam, as shown in Figure 3, was procured from various Styrofoam packaged goods like fridges, electronics, and glassware. It was systematically broken into chunks matching the size of coarse aggregates and served as a partial substitute for conventional coarse aggregate. Potable water was used for the fresh concrete mix. The plasticizer used in the experimental procedure is Conplast SP430, as shown in Figure 4. It complies with IS 9103:1999 [13] and ASTM C-494 [14] Type 'F' as a high-range water-reducing agent.

Figure 1: River sand

Figure 2: ½ inch granite

Figure 3: Styrofoam

Figure 4: Complast SP340pPlasticizer

2.2 Methods

2.2.1 Mixing and batching

A mix ratio of 1:2:4 was used for the proportioning of the constituents. In the production of Styrofoam concrete, the coarse aggregates were replaced by 5%, 10%, 15%, 20%, 25%, and 30% by volume. Specimens were cast for each group of the experimental procedure in order to carry out the strength tests on the specimens for 7, 14, 28, 56, and 90days curing period. For each strength test to be carried out, multiple samples were tested, and the average strength value was obtained. The mixes are outlined below:

i) Mix 1 - Concrete replacing 5% coarse aggregate with EPS (Mix 1).
ii) Mix 2 - Concrete replacing 10% coarse aggregate with EPS (Mix 2).
iii) Mix 3 - Concrete replacing 15% coarse aggregate with EPS (Mix 3).
iv) Mix 4 - Concrete replacing 20% coarse aggregate with EPS (Mix 4).
v) Mix 5 - Concrete replacing 25% coarse aggregate with EPS (Mix 5).
vi) Mix 6 - Concrete replacing 30% coarse aggregate with EPS (Mix 6).

In this experimental procedure, the batching by volume method was employed. Consistency in the batching of constituents was achieved with the use of a standard head pan, which was struck off and levelled when full. The mixture proportions in their dry masses are displayed in Table 1.

Table 1: Concrete mixture proportions

	Cement (kg)	Sand (kg)	Granite (kg)	Styrofoam (kg)	Water (kg)	Admixture (cm^3)
Mix 1	6.625	13.25	25.175	0.0126	5.3	66.25
Mix 2	6.625	13.25	23.850	0.0252	5.3	66.25
Mix 3	6.625	13.25	22.525	0.0378	5.3	66.25
Mix 4	6.625	13.25	21.200	0.0504	5.3	66.25
Mix 5	6.625	13.25	19.875	0.0630	5.3	66.25
Mix 6	6.625	13.25	18.550	0.0756	5.3	66.25

2.2.2 Physical, fresh, and hardened tests on concrete

Sieve analysis was carried out on the fine and coarse aggregates in line with BS EN 1260 to determine the particle size distribution. The Styrofoam was carefully shredded into coarse aggregate sizes to be used as a partial replacement for granite. The slump test was used to determine the consistency or workability of fresh concrete. It was determined with the use of a slump cone. The specimens were cast and demolded, followed by concrete curing to ensure continued hydration and, consequently, continued strength gain in concrete. The specimens were cured for 7, 14, 28, 56, 90, and 120 days, respectively. The test on hardened concrete includes compressive strength, which was carried out in line with BS EN 12390-3 [15], split tensile test also in line with BS EN 12390-3 [15], and the Flexural strength test was carried out in line with BS EN 12390-5 [16]. The specimens were subjected to three-point bending. Microstructural analysis, SEM-EDX, was conducted to determine the inherent properties and compound composition of the concrete produced. Polished cross-sections for SEM/EDX were prepared by vacuum epoxy impregnation of 20×20×10 mm blocks (EpoFix, Struers) under 0.5 kPa vacuum for 8 min, followed by slow return to atmospheric pressure and cure at 25 °C for 24 h. Mounted blocks were ground and polished using SiC papers. Between stages, samples were ultrasonically cleaned for 5 min and dried in a desiccator. Specimens requiring carbon mapping were left uncoated and imaged in low vacuum (40 Pa); other specimens were coated with ~5 nm Au/Pd. Samples of concrete produced were prepared and analysed.

3. RESULTS AND DISCUSSIONS

3.1 Sieve Analysis of Aggregates

The results of the sieve analyses of the fine aggregate (sand) and the coarse aggregate (granite) are displayed in Figure 5. The fineness modulus of the coarse aggregates was found to be 6.34, and that of 2.86 for sand, which is an indication that the coarse aggregates are uniformly graded with a balance between fine and large particles, resulting in fewer voids. It also reduced the packing density of concrete, leading to enhanced strength and reduced permeability.

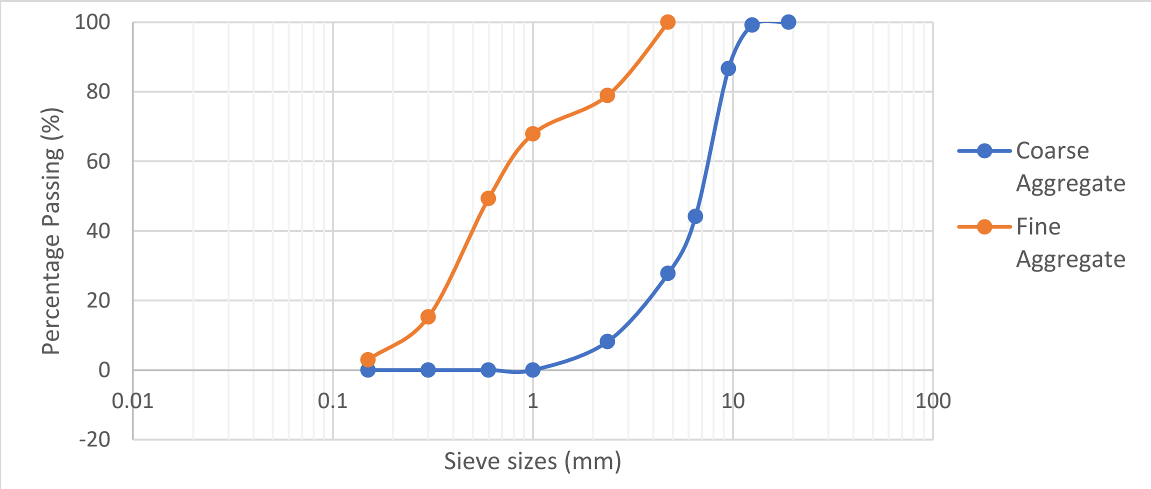

Figure 5: Sieve analysis result of aggregates

3.2 Slump Test

The results of the slump tests show that as the percentage replacement of the expanded polystyrene increased in the concrete, the slump value increased. It can be seen that the largest slump value is obtained by Mix 6, which has a 30% replacement of coarse aggregate. The lowest slump value is obtained by Mix 1 with a 5% replacement of coarse aggregate. The graph in Figure 6 shows the relationship between the slump value and the percentage replacement with expanded polystyrene to be directly proportional. This relationship can be attributed to the hydrophobic nature of Styrofoam, which would reduce the absorption properties of the concrete specimen with its (Styrofoam) increasing presence in the mix.

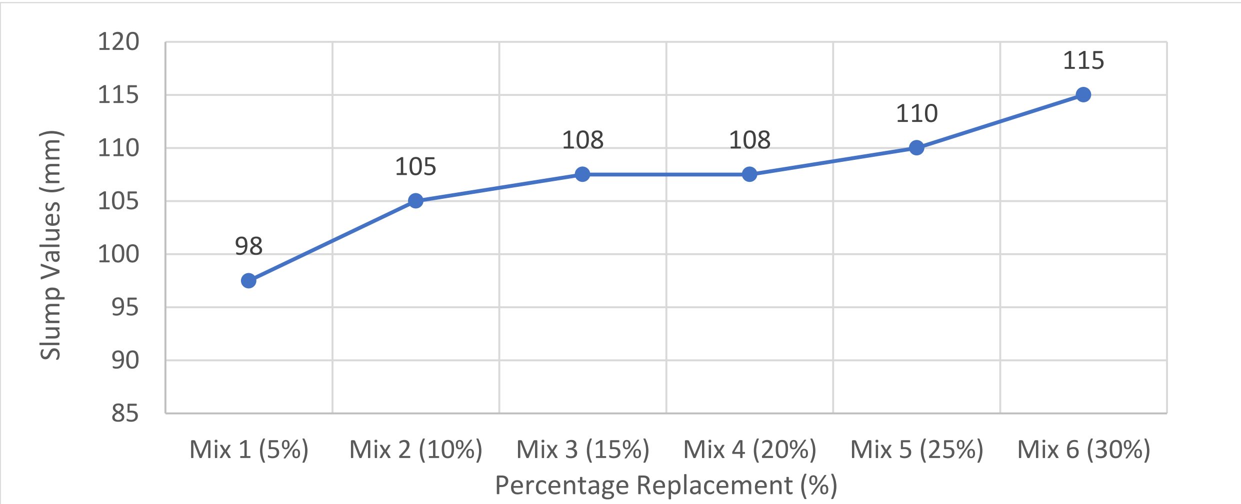

Figure 6: Slump test results

3.3 Dry Density Test

The dry density test helps to determine whether the EPS-concrete falls into lightweight concrete classes. The classification is essential for deciding its suitability for structural or non-structural applications. The results of dry bulk density of the concrete samples are shown in Figure 7. The dry bulk density of the mixes was found to be inversely proportional to the coarse aggregate replacement percentage. The much lower relative density of the Styrofoam (0.018) was apparently the cause for the reduced bulk density of the samples, bearing in mind that the relative density of the coarse aggregate used is 2.6. As such, the higher the amount of Styrofoam in the concrete, the lower its dry density. Mix 6 had the lowest dry density (2374kg/m^3) and Mix 1 had the highest (2577kg/m3). Even with this impressive weight reduction, it should be noted that all the mixes still fell under the normal-weight classification of concrete (2200kg/m^3 – 2600kg/m^3) [16]. The use of EPS reduces the unit weight of concrete. The current study produced better results and is in line with Mohammed et al. 2023 [17] findings. Since the dry density is linked to porosity and permeability, the test provides insight into the likely durability of the concrete. Lower densities may indicate higher void content, affecting resistance to water penetration and an aggressive environment. The current study shows that the use of 5% EPS will produce a durable concrete.

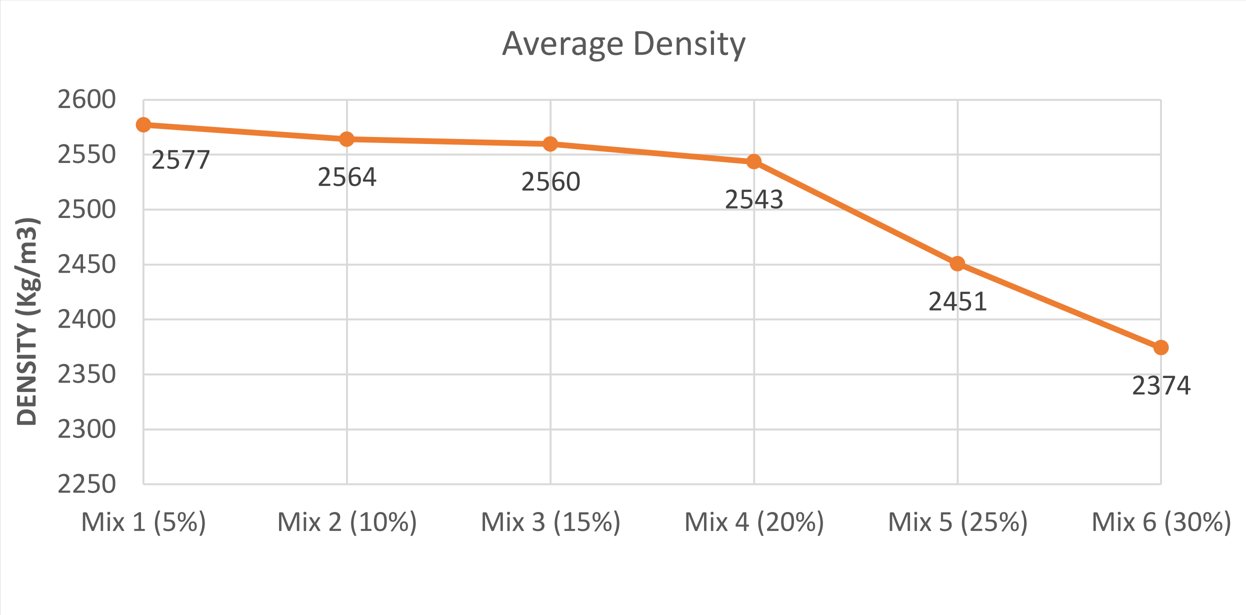

Figure 7: Average density of all samples of the mix against aggregate

3.4 Compressive Strength Test

The compressive strength of concrete was determined following the specifications and recommendations of [15]. Figure 8 displays the compressive strength values for all mixes across six curing periods (7, 14, 28, 56, 90, and 120 days). It is evident that there is an approximately inverse relationship between Styrofoam content in the concrete and its compressive strength. As shown in Figure 8, higher amounts of Styrofoam resulted in lower strength in the concrete. For example, Mix 1, with just 5% coarse aggregate replacement, achieved the highest compressive strength of 15.86 N/mm^2, while Mix 6, with 30% replacement, had the lowest at 9.71 N/mm^2. Although EPS reduces strength, a 5% partial replacement still maintains sufficient strength for use in mass concrete, non-structural elements, and some lightweight structural applications, providing a balance between waste reduction, sustainability, thermal properties, and strength. The current study produced results consistent with those of Muhammad et al. (2019) [18], who also used Styrofoam as a matrix for coarse aggregate to produce concrete.

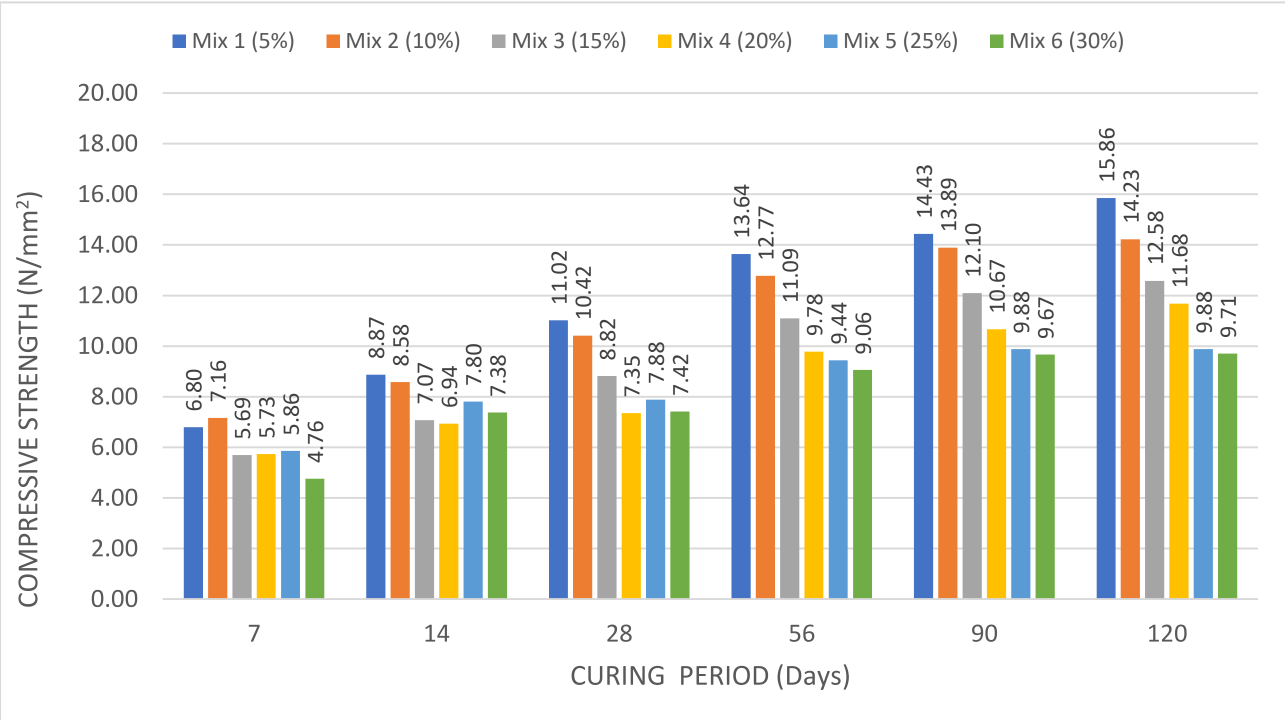

Figure 8: Compressive strength at each curing period replacement

3.5 Split Tensile Test

The split tensile measures the concrete's ability to withstand indirect tensile stresses. Since concrete is inherently weak in tension, this test is crucial in assessing how EPS replacement further affects the tensile capacity of concrete. The splitting strength of concrete, also known as the split-tensile strength of concrete, was obtained in accordance with the specifications and recommendations of [17]. Figure 9 shows a steady tensile strength development in the concretes as their curing ages increased. The peak tensile strengths were observed in Mix 1, which is analogous to the reference concrete as far as this study is concerned. The concrete that followed closely after was Mix 2, which was at any given point between just 0.5-4.5% lower. Mix 3 also boasted impressive results, with the remaining mixes displaying proportionally decreasing results. Figure 9 clearly shows a correlation between Styrofoam content and split tensile strength; the higher the amount of Styrofoam in the concrete, the lower its split tensile strength and vice versa. Though concrete is generally strong in compression and weak in tension, these values are still important in the design of concrete members that would be subjected to transverse shearing, twisting, shrinking, and thermal expansion and contraction. This current study shows that 5% optimum percentage of Styrofoam replacement balances weight reduction with adequate tensile performance.

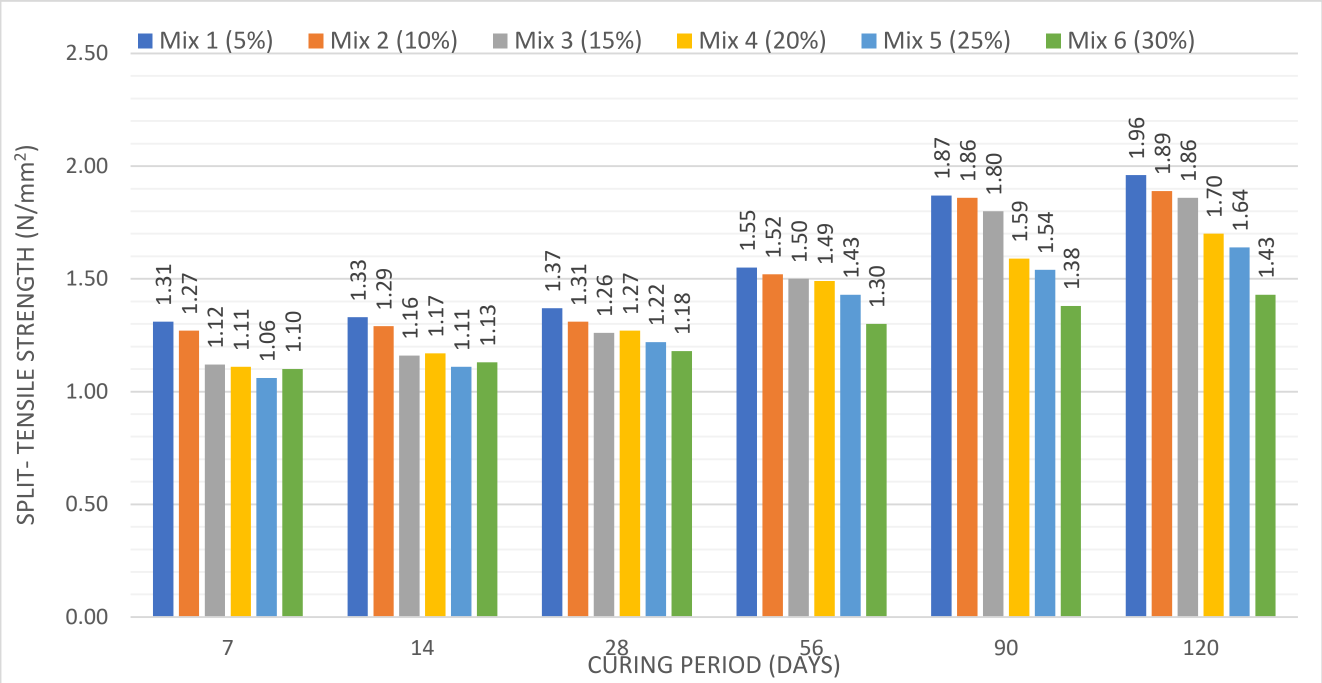

Figure 9: Split tensile strength of all samples at each curing period

3.6 Flexural Strength Test

The flexural strength test evaluates how well EPS-concrete can resist bending and tensile stresses at the bottom fiber of beams or slabs. This role is critical since Styrofoam reduces tensile resistance, and flexural loading is often the governing failure mode in structural elements. The results of the flexural strength test after 60, 90, 120, and 125 days, respectively, are displayed in Figure 10. The results show something familiar, with Mix 1 having the highest flexural strength at 63 and 90 days of curing, and Mix 2 and Mix 3 following close behind. By 120 days, however, the strengths of Mix 2 and Mix 3 grew by 9.9% and 14.5% respectively, from just 30 days prior. This skyrocketed their flexural strengths and saw them having comparable and even higher values than Mix 1, which had just a 3.8% strength growth in the same timeframe. At 125 days, this growth persisted and had Mix 2 and Mix 3 significantly higher than Mix 1. The results showed that the bonding action between the Styrofoam pellets and the reinforced cement matrix improved the flexural strength of the concretes at later ages by as much as 8.5% at a coarse aggregate replacement by Styrofoam of 15%. This holds prospects for the high and continuous strength gain that can be realized in the long-term use of the EPS-concrete. It should be noted that despite the reduction, the lightweight nature of EPS-concrete provides a unique strength-to-density ratio, and it is scientifically important where reduced dead load is more valuable than high flexural resistance. The current study outcome is in line with Solikin et al. (2020) [19] findings. The study also provides a foundation for developing improved EPS-based composites through reinforcement or admixture.

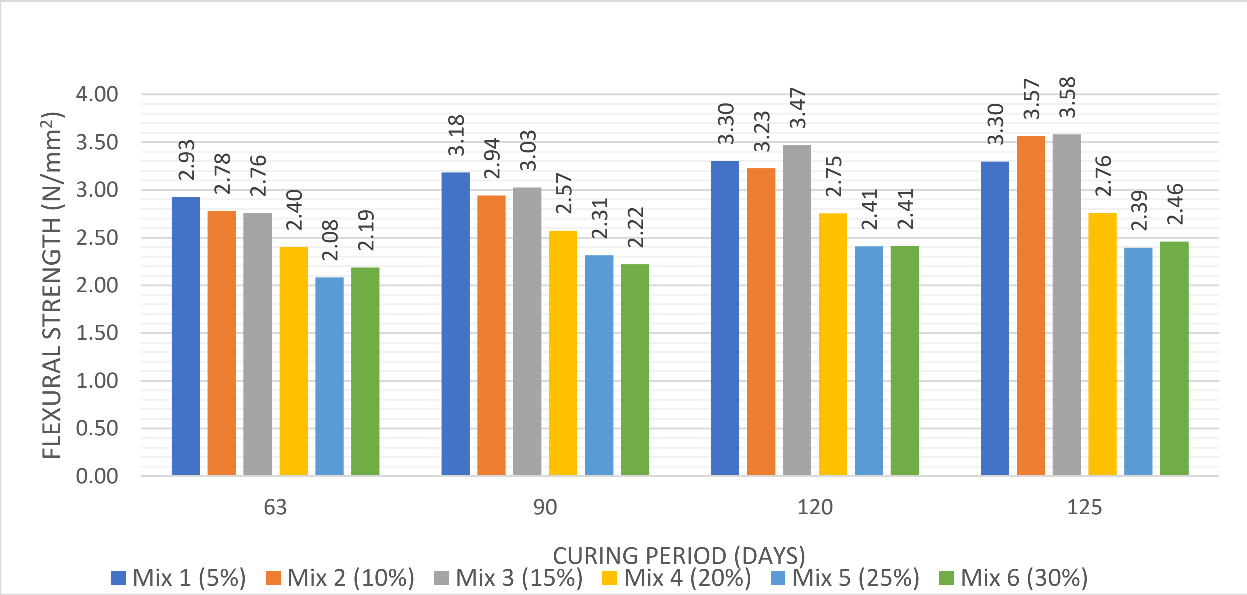

Figure 10: Flexural strength at each curing period

3.7 SEM-EDX Analyses

Microstructural analysis, SEM-EDX, was carried out to investigate the intrinsic characteristics and elemental composition makeup of selected concretes. This is useful to confirm the presence of hydration products and to detect any chemical interaction or lack of bonding between EPS and cement paste. It also allows us to know the interfacial transition zone (ITZ) between the cement paste and Styrofoam particles, which is the weakest region in EPS-concrete, and it also explains why mechanical properties decrease with higher EPS replacement. To achieve this, a control specimen was prepared and cured for 28 days. Mix 1, being the highest performing concrete, was also picked to perform this supplementary examination. The SEM-EDX analysis was conducted on the remnants left over from the compressive and split-tensile tests after 28 days of curing. The results of the control concrete and Mix 1 after 28 days of curing are presented in Figure 11 and Figure 12, respectively. Figure 11 shows the formation of ettringite and a fairly regular crystalline structure in the control concrete. Mix 1, however, as shown in Figure 12, comprised of irregularly-shaped Styrofoam pellets that bonded to the other concrete constituents. The semi-elastic nature of the Styrofoam must have bridged the cement matrix and reduced the brittleness and fragility of the concrete due to the efficient transmission of applied loads through the mix. This could explain the high and impressive mechanical properties observed in Mix 1. The EDS images revealed that Mix 1 and the control concrete had similar elemental compositions, and so the mineralogical effect of the coarse aggregate replacement was not too great.

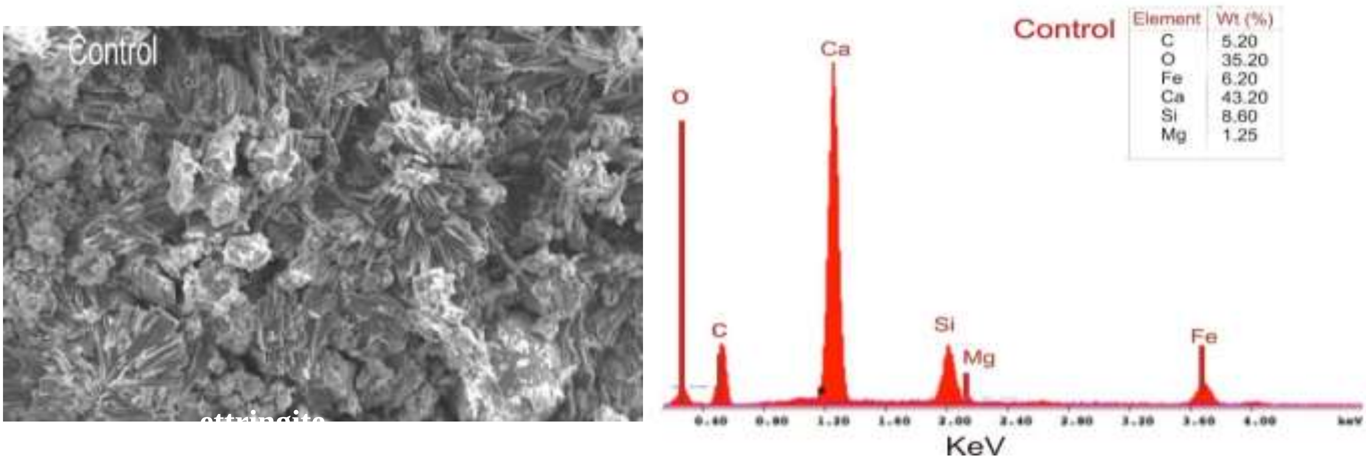

Figure 11: SEM-EDS results of control concrete after 28 days

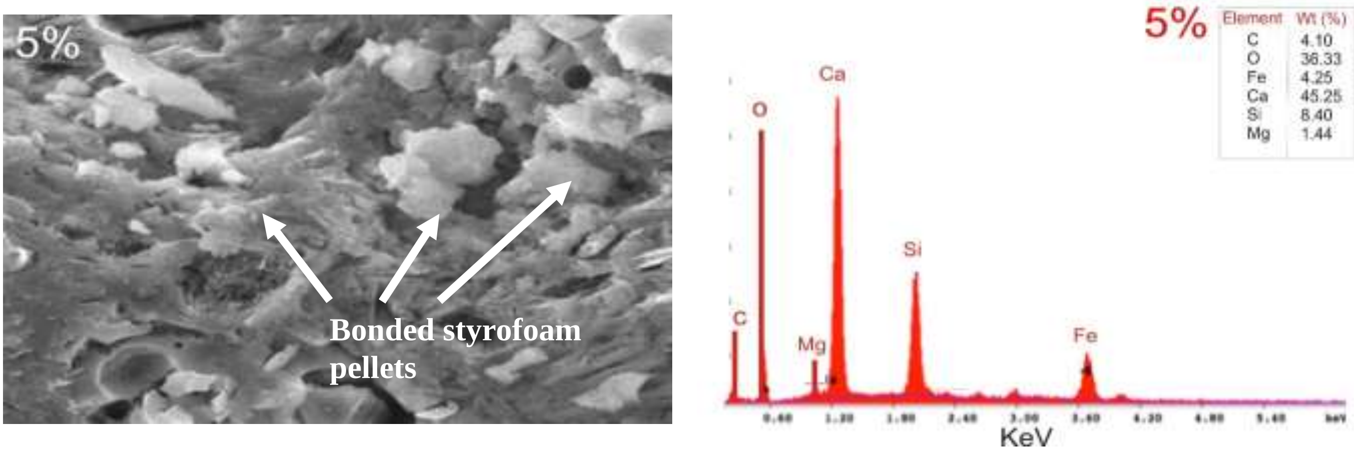

Figure 12: SEM-EDS results of Mix 1 after 28 days

4. CONCLUSIONS

The results of this study show that the use of expanded polystyrene as a replacement for coarse aggregate is achievable. The following conclusions are drawn from the study.

i. The increase in the volume of EPS in the concrete shows a directly proportional increase in the slump value.
ii. The much lower relative density of the Styrofoam reduced the bulk densities of the samples. Mix 6 had the lowest dry density (2374kg/m^3), and Mix 1 had the highest (2577kg/m^3) and showing that there is an inverse relationship between the amount of Styrofoam present and the bulk density. Even with this impressive weight reduction, all the mixes still fell under the normal-weight classification of concrete (2200kg/m^3 – 2600kg/m^3).
iii. The compressive strength results showed that higher amounts of Styrofoam present resulted in reduced strength in the concrete. As such, Mix 1, with 5% coarse aggregate replacement, had the highest compressive strength values.
iv. The peak tensile strengths were observed in Mix 1. The concrete that followed closely after was Mix 2, which was at any given point between just 0.5 - 4.5% lower. Mix 3 also boasted impressive results, with the remaining mixes displaying proportionally decreasing results. Expectedly, the Styrofoam content and the tensile strength maintained an inverse relationship.
v. The flexural strength results showed that the bonding action between the Styrofoam pellets and the reinforced cement matrix improved the flexural strength of the concretes at later ages by as much as 8.5% at a coarse aggregate replacement by Styrofoam of 15%. The flexural strengths then proceeded to a sharp decrease at further increases in Styrofoam content.
vi. SEM–EDS in Styrofoam-modified concrete provides a microstructural and chemical explanation for the observed changes in strength and durability. It visualizes the weak EPS–cement bond, confirms pore structure, and analyzes hydration products. The semi-elastic nature of the Styrofoam has bridged the cement matrix and reduced the brittleness and fragility of the concrete due to the efficient transmission of applied loads through the mix. This could explain the high and impressive mechanical properties observed in Mix 1.
vii. Given all the findings, the partial replacement of 5% represented the mix that attained the most desirable properties.
viii. EPS can be safely used as a partial coarse aggregate replacement in concrete, provided that appropriate structural considerations, mix design, fire precautions, and construction practice are followed. The advantages of EPS as lightweight aggregates and thermal insulation make it safe and suitable for non-structural and light structural applications.

ACKNOWLEDGMENT

The authors wish to thank the management of Covenant University and Abiola Ajimobi Technical University for the platform made available for this research work

REFERENCES

[1] Parhizkar, T., Najimi, M., & Pourkhorshidi, A.R. (2012). Application of Pumice Aggregate in Structural Lightweight Concrete. *Structural Asian Journal of Civil Engineering (Building and Housing),* 13(1), 43-54.
[2] Geoffrey, N.M., Raphael, N.M., Walter, O.O., & Silvester, O.A. (2012). Properties of Pumice Lightweight Aggregate. *Civil and Environmental Research*, 2(10), 58-68.
[3] Mashava, C. T., & Elsaigh, W. A. (2023). Partial replacement of coarse aggregate by expanded polystyrene thermocol. *Materials Today: Proceedings*, (2023), 86, 7-13.
[4] Ngandu, C.N. (2020). Review on Alternatives of Aggregates with Alternative Materials in Eastern Africa. *Selected Scientific Papers-Journal of Civil Engineering*, 15(2), 17-28.

[5] Ngene B.U**.,** Bamigboye G.O**.** Osato. A. (2019). Challenges of using non-degradable waste material polystyrene packing in reinforced concrete design and construction. *Proceedings of the Interdependence between Structural Engineering and Construction Management Conference*, 2019. 41.

[6] Panda, A. K., Singh, R. K., & Mishra, D. K. (2010). Thermolysis of Waste Plastics to Liquid Fuel: A Suitable Method for Plastic Waste Management and Manufacture of Value-Added Products—A World Perspective, *Renewable and Sustainable Energy Reviews,* paper 14, 233-248.

[7] Alhnifat, R. S., Abdel-Jaber, M. T., & Al-Dala'ien, R. N. (2023). Behavior of lightweight concrete incorporating pozzolana aggregate and expanded polystyrene beads. *Engineered Science*, *25*, 934.

[8] Vandhiyan, R., Rajeth, B., & Nagarajan, M. (2016). A Study on Mechanical Properties of Concrete by Replacing Aggregate with Expanded Polystyrene Beads. *Global Journal of Engineering Science and researchers (JSER), Andhiyan*, 3(11), 7-13.

[9] Maghfouri, M., Alimohammadi, V., Gupta, R., Saberian, M., Azarsa, P., Hashemi, M. & Roychand, R. (2022). Drying shrinkage properties of expanded polystyrene (EPS) lightweight aggregate concrete: A review. *Case Studies in Construction Materials*, 16, e00919.

[10] Liu, N., & Chen, B. (2014). Experimental Study of the Influence of EPS Particle Size on the Mechanical Properties of EPS Lightweight Concrete. *Construction and Building Materials*, 68, 227-232.

[11] Gambo, J. (2023). Experimental study on partial replacement of fine aggregate by Expanded polystyrene beads in concrete. *Mesopotamian Journal of Civil Engineering*, 18-25.

[12] Alam, B. Ullah, Z., Jan, F.U., Shahzada, K., & Afzal, S. (2013). Investigation of Styrofoam as Lightweight aggregate. *International Journal of Advanced Structures and Geotechnical Engineering*, 2(2), 50-54.

[13] *Bureau of Indian Standards 9103. Specification for Concrete Admixture*. Bureau of Indian Standards IS9103: (1997).

[14] *American Society for Testing and Materials, Standard Specification for Chemical Admixtures for Concrete.* ASTM International, West Conshohocken, PA, ASTM C494/C494M-17; (2017).

[15] *British Standards Institute, Tracked Changes. Testing hardened concrete. Compressive strength of test specimens*. BS EN 12390-3 (2019).

[16] *British Standards Institute, Testing hardened concrete. Flexural strength of test specimens*. BS EN 12390-5 (2019)

[17] Mohammed, I.I., Nariman, N.A., Shakor, P., Ismail, O., & Rizgar, K. (2023). Post-Fire Mechanical Properties of Concrete Incorporating Waste EPS (Styrofoam) as Aggregate Replacement. *Civil Engineering*, 4(2), 359-372.

[18] Asnan, M.N., Noor, R., & Azzahra, R. (2019). Utilization of Tyrofoam-Matrix for Coarse Aggregate to Produce Lightweight Concrete. *International Journal of Engineering & Technology*, 8(1), 207-212.

[19] Solikin, M., Zaini, A. N., Setiawan, B., & Asroni, A. (2020). Flexural Strength Analysis of Styrofoam Concrete Hollow Panel Walls Incorporated with High-Volume Fly Ash. *Civil Engineering and Architecture*, 8(3), 320-325.