Study of the Effect of Imported and Locally Sourced Aggregates on the Physical and Mechanical Properties of Concrete in Somalia

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Abstract The present study evaluates the performance of locally sourced and imported aggregates in Somalia, focusing on their impact on the physical and mechanical properties of concrete. Four different aggregates were investigated: Baidoa and Galkayo (locally sourced) and Oman and Dubai (imported). Concrete cubes of 150 mm x 150 mm x 150 mm were prepared and tested under two mix designs, M25 and M30, at curing durations of 7 and 28 days. Five key tests were conducted: compressive strength, slump test, Los Angeles abrasion, water absorption, and sieve analysis. Results indicate that the Oman and Galkayo aggregates exhibited the highest compressive strength in M25, while the Galkayo and Dubai aggregates performed best in M30. The Los Angeles abrasion and water absorption tests revealed that Dubai and Galkayo aggregates had superior durability properties. The sieve analysis showed significant variations in size distribution among the aggregates. Findings provide a foundation for optimizing concrete mix designs in Somalia, balancing availability, cost, and performance. Further research on long-term durability and microstructural properties using SEM analysis is recommended.

Keywords Aggregate Comparison, Concrete Performance, Compressive Strength, Local Aggregate, Imported Aggregate, Somalia

1. Introduction

Concrete is the most widely used construction material worldwide, with an annual consumption exceeding 11 billion metric tons [1] [2]. Its extensive use is attributed to its versatility, durability, and economic feasibility. Aggregates, which constitute approximately 80% of the total volume of concrete, play a crucial role in determining its mechanical properties, workability, and durability[3-9]. The quality, type, and origin of aggregates significantly impact the performance of concrete, making aggregate selection a critical factor in construction [9-16].

In Somalia, aggregates are sourced both locally and internationally. However, limited research exists comparing their impact on concrete performance. Many construction projects in Somalia rely on imported aggregates due to concerns over the quality and consistency of locally available materials. The absence of standardized testing and evaluation of Somali aggregates creates uncertainty in their application for structural projects. Therefore, a systematic study is necessary to assess and compare the performance of imported aggregates from Oman and Dubai with locally sourced aggregates from Baidoa and Galkayo.

Despite the increasing demand for sustainable and cost-effective construction materials, there is a lack of comprehensive studies assessing the suitability of local aggregates for concrete production in Somalia. Existing studies from other regions indicate that variations in aggregate characteristics, such as particle size distribution, water absorption, and abrasion resistance, influence concrete properties significantly. However, no systematic research has been conducted to analyze Somali aggregates in comparison to imported alternatives.

Understanding the influence of different aggregate sources on concrete properties is essential for cost reduction, structural durability, and sustainable construction. If locally sourced aggregates exhibit comparable or superior performance, this could reduce reliance on expensive imported materials, supporting the local economy and minimizing transportation-related environmental impacts. Additionally, this research provides engineers, policymakers, and construction professionals with critical data for material selection and mix optimization.

This study fills a crucial research gap by conducting a comparative evaluation of Baidoa, Galkayo, Oman, and Dubai aggregates, providing scientifically backed insights into their suitability for concrete applications. The findings will contribute to improved construction practices, ensuring structurally sound, durable, and cost-effective infrastructure development in Somalia.

2. Materials and Methods

2.1. Materials

The materials used in this study included cement as the primary binding agent and sand as the fine aggregate. Four different types of coarse aggregates were utilized, categorized into locally sourced (Baidoa and Galkayo) and imported (Oman and Dubai) varieties. These aggregates were integral to the concrete mix designs being tested. The concrete cubes, each measuring 150 mm x 150 mm x 150 mm, were prepared using a consistent water-cement ratio of 0.5. The selected aggregates underwent various tests to assess their physical and mechanical properties, which were crucial for evaluating their performance in concrete applications.

2.2. Methods

The study employed a comprehensive set of methods to evaluate the properties and performance of the selected aggregates. Sample preparation involved casting concrete cubes of 150 mm x 150 mm x 150 mm using two mix designs, M25 and M30. Each aggregate type was tested with three cubes at curing periods of 7 days and 28 days to assess the development of strength over time.

Sieve analysis was performed to characterize the fineness modulus and particle size distribution of the aggregates. Aggregates were subjected to a sieve stack with progressively smaller apertures, and the weight of the retained material on each sieve was measured.

The Los Angeles Abrasion Index (LAAI) test was used to assess the resistance of the aggregates to mechanical degradation. Aggregate samples, along with steel balls, were placed in a rotating drum and subjected to 500 revolutions. The percentage of material passing a 1.7 mm sieve after the test was recorded as the Los Angeles Abrasion Value, indicating the aggregate's durability under abrasive conditions.

The water absorption test determined the aggregates' capacity to absorb water, a critical factor in calculating the water-cement ratio in concrete mixes. The aggregates were weighed in both oven-dry and saturated surface-dry (SSD) conditions, and the difference in weight was used to calculate the absorption percentage.

The workability of the concrete mixes was evaluated by conducting slump tests according to the relevant ASTM standard. For each mix, a standard slump cone was filled with fresh concrete in three equal layers. Each layer was compacted by rodding 25 times with a standard steel rod, ensuring uniform distribution and compaction throughout the cone. After filling, the mold was removed, and the difference in height between the original and slumped concrete was measured to assess the concrete's consistency and workability.

Finally, the compressive strength of the concrete cubes was tested at 7 and 28 days. The cubes were subjected to increasing compressive loads until failure using a compression testing machine. The maximum load sustained by each cube was recorded, and the compressive strength was calculated by dividing this load by the cross-sectional area of the cube. These tests provided vital data on the mechanical properties of the concrete made with different aggregates, allowing for a comparative evaluation of their performance.

3. Results and Discussions

3.1. Size Distribution of Aggregate

The particle size distributions of aggregates from Dubai, Oman, Baidoa, and Galkayo in Figures 1, 2, 3, and 4 show notable differences in their gradation, influencing their potential applications in construction. The Dubai aggregate is characterized by a majority of particles retained on the 20 mm sieve, accounting for 54.54% of the total. This indicates a coarse nature, with only a small fraction of particles passing through finer sieves. For instance, the percentage passing the 200 sieve is merely 0.057%. This distribution suggests that the Dubai aggregate might be suitable for applications requiring high strength but may pose challenges in terms of workability due to the lack of finer particles.

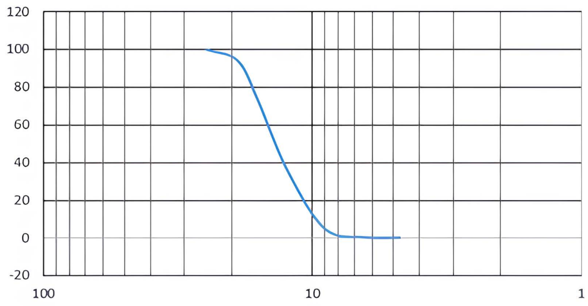

Figure 1. Particle size distribution curve for Dubai aggregate

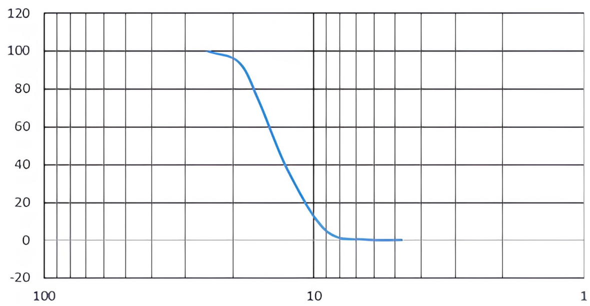

Figure 2. Particle size distribution curve for Oman aggregate

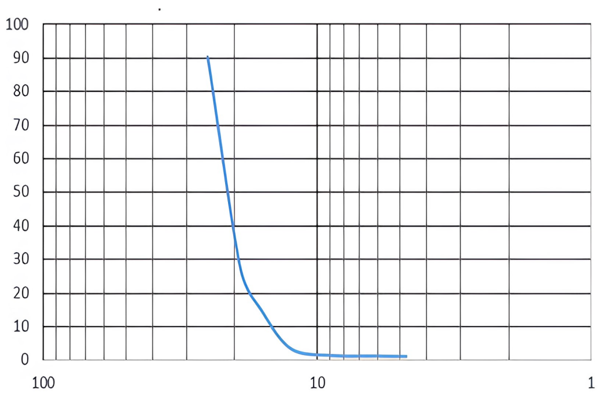

Figure 3. Particle size distribution curve for Baidoa aggregate

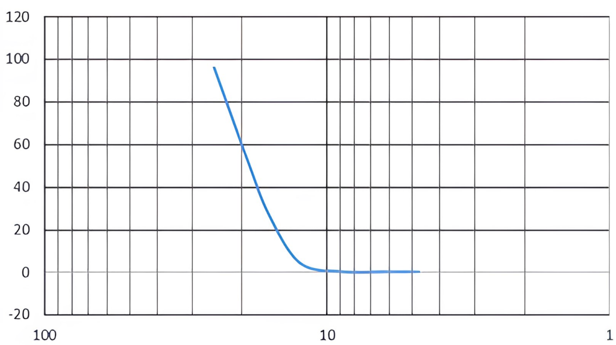

Figure 4. Particle size distribution curve for Galkayo aggregate

In contrast, the Oman aggregate presents a more balanced distribution across various sieve sizes. The largest proportion of particles, 36.46%, is retained on the 40 mm sieve. This suggests a mix of course and medium-sized particles, providing a smoother gradation compared to Dubai's aggregate. Such a distribution can enhance both the workability and density of concrete, making it versatile for different construction applications.

The Baidoa aggregate is distinct in having a significant amount of material retained on the 10 mm sieve, with 63.07% of the total. After this sieve, there is a noticeable drop in retained aggregate, with only 2.06% retained on the 60 mm sieve. This indicates a dominance of medium-sized particles with relatively fewer fines, which could result in a good balance between strength and workability, depending on the specific construction requirements.

The Galkayo aggregate has a notable amount of coarse particles, with 44.17% retained on the 10 mm sieve. Like the Dubai aggregate, there is a significant reduction in the percentage passing as the sieve size decreases, indicating very little material passing through the 140 and 200 sieves. This coarse distribution suggests that the Galkayo aggregate could be suitable for structural applications where strength is paramount, though it may require additional considerations for achieving the desired workability in concrete mixes.

Overall, the gradation of these aggregates influences their mechanical properties and suitability for various construction projects. Well-graded aggregates, like those from Oman and potentially Baidoa, provide better packing density and lower void content, which can enhance concrete strength and durability. In contrast, gap-graded or poorly graded aggregates, as seen with the Dubai and Galkayo samples, might lead to higher void content, requiring more binder or posing segregation risks. Selecting the appropriate aggregate gradation is crucial to meeting the specific requirements of a construction project, balancing factors such as workability, strength, and durability.

3.2. Water Absorption

The water absorption percentages indicate the amount of water that the aggregates can absorb, which is an important property for understanding their suitability in various construction applications. Figure 5 shows aggregate samples submerged in water for water absorption testing.

Figure 5. Water absorption test

In Table 1, the water absorption results for aggregates from Baidoa, Oman, Dubai, and Galkayo reveal distinct differences in their porosity and potential impact on concrete properties. The Baidoa aggregate exhibits the highest water absorption percentage at 0.55%. This value indicates a relatively high porosity, suggesting that the Baidoa aggregate can absorb more water compared to the other aggregates. Such a characteristic can influence the workability of concrete and may require adjustments in the water-cement ratio to achieve the desired consistency.

The Oman aggregate shows a moderate level of water absorption at 0.45%. This indicates a fair amount of porosity, less than Baidoa but still significant. The moderate water absorption suggests that the Oman aggregate has a balanced structure that can support both workability and strength in concrete mixes. This balance can be advantageous in various construction applications, where moderate absorption is not detrimental to the overall concrete quality.

The Dubai aggregate has the lowest water absorption percentage among the samples, at 0.22%. This low absorption rate indicates a dense and less porous aggregate structure. Such aggregates are typically desirable in high-strength concrete applications, where minimal water absorption is essential for maintaining strength and durability. The dense nature of the Dubai aggregate can contribute to the overall stability and robustness of the concrete.

Lastly, the Galkayo aggregate displays a water absorption percentage of 0.39%, which falls between the values for Baidoa and Dubai. This suggests that the Galkayo aggregate has a moderate level of porosity, similar to the Oman aggregate but slightly lower. The moderate absorption rate implies that Galkayo aggregates can provide a balance between durability and workability in concrete mixes, making them suitable for a wide range of applications.

In summary, the water absorption characteristics of these aggregates offer valuable insights into their suitability for different types of concrete. High absorption rates, as seen in the Baidoa aggregate, indicate higher porosity and potential implications for concrete workability and durability. In contrast, low absorption rates, like those observed in the Dubai aggregate, suggest a dense structure suitable for high-strength concrete. The moderate absorption rates of the Oman and Galkayo aggregates present a balanced option for general construction needs, where a compromise between workability and strength is essential.

3.3. Hardness Properties of Aggregate

The Los Angeles abrasion test is a standardized procedure used to measure the durability and abrasion resistance of aggregates, ultimately determining their suitability for use in applications like pavements, concrete, and asphalt. The test involves placing a representative sample of the aggregate, sieved to a specific size, inside a rotating steel drum along with a predetermined number of steel balls. As the drum rotates at a constant speed for a set number of revolutions, the steel balls tumble and impact the aggregate, simulating real-world wear and tear. After the test, the aggregate is sieved, and the amount passing through a specific sieve size is measured and expressed as a percentage of the original weight, known as the Los Angeles abrasion value. A lower value indicates higher abrasion resistance and thus, greater suitability for demanding applications.

The results in Table 2 suggest that the Dubai aggregate exhibited the highest resistance to abrasion, followed by the Galkayo, Oman, and Baidoa aggregates, respectively. The Dubai and Galkayo aggregates, with their lower abrasion loss percentages, would be well-suited for use in heavy-duty infrastructure projects that require materials to withstand significant wear and tear, such as dams, bridges, and foundations. These types of structures are subjected to intense stresses and require aggregates with exceptional durability to maintain their structural integrity over time.

Table 1. Water absorption result for different types of aggregate

No	Description	Baidoa	Oman	Dubai	Galkayo
1	Weight of wet aggregate after 24hr water curing	2002	2001	1861	1788
2	Weight of oven Dried aggregate W3	1991	1992	1857	1781
3	Water absorption = W2-W3/W3 X 100	0.55%	0.45%	0.22%	0.39%

Table 2. Los Angeles abrasion test result

No	Description	Dubai	Oman	Baidoa	Galkayo
1	Total gram of aggregate sample = (W)	5000grm	5000grm	5000grm	5000grm
2	Mass of empty = (Mc)	131grm	131grm	474grm	473grm
3	mass of empty + retained aggregate= mgr.	4305grm	4124grm	4286grm	4127grm
4	mass of retained aggregate = Mcr-Mc	4174grm	3993grm	3814grm	3654grm
5	mass of passed aggregate = Mr-W	826grm	1007grm	1186grm	1346grm
6	Abrasion value Mr/W x 100	16.52%	20.14%	23.7%	18%

In contrast, the Baidoa aggregate, with its higher abrasion loss, may be more appropriate for less demanding applications such as sidewalks, low-traffic roads, and general building construction. While these applications do not require the same level of abrasion resistance, the Baidoa aggregate's lower performance in the Los Angeles Abrasion Test indicates that it may be more susceptible to wear and deterioration over time.

The Oman aggregate, with an intermediate abrasion loss of 20.14%, could potentially be used in a wider range of construction projects, from medium-duty infrastructure to building construction, depending on the specific requirements and load-bearing demands of the project.

3.4. Slump Test

The results in Figure 6 indicate varying degrees of slump, which can be attributed to the inherent characteristics of the aggregates and their interactions with the other concrete constituents.

The Dubai aggregate produced the highest slump, with values of 11.8 cm and 8 cm. This suggests that the Dubai aggregate results in a highly workable concrete mix, with excellent flowability and ease of placement. Aggregates with a more rounded, smooth surface texture and a well-graded particle size distribution tend to improve the workability of concrete by reducing the internal friction between the particles. The Dubai aggregate's properties likely contribute to this enhanced workability.

In contrast, the Galkayo aggregate exhibited the lowest slump, with values of 7.2 cm and 8 cm. This lower slump indicates a less workable concrete mix, which may require more effort during placement and compaction. Aggregates with a more angular, rough surface texture and a less-than-ideal particle size distribution can increase the internal friction within the concrete mixture, leading to a stiffer and less flowable consistency.

The Baidoa and Oman aggregate mixes demonstrated a moderate level of workability, with slump values ranging from 7.1 cm to 11 cm. This suggests a balance between flowability and cohesiveness, making these aggregates suitable for a wider range of concrete applications.

The differences in slump can be attributed to several factors, including the physical and chemical properties of the aggregates, the mix design, and the interaction between the aggregates and the other concrete constituents (cement, water, admixtures, etc.).

The findings from the slump test results can be useful in selecting the most appropriate aggregate source for a given concrete application. Contractors and engineers can utilize this information to make informed decisions about the concrete mix design, placement methods, and compaction requirements based on the specific needs of the project.

For instance, the highly workable concrete mix with the Dubai aggregate may be well-suited for applications that require excellent flowability, such as self-compacting concrete or concrete pumping. The moderately workable Baidoa and Oman aggregate mixes could be suitable for a broader range of applications, where a balance between workability and cohesiveness is desired. The less workable Galkayo aggregate mix may be better suited for applications where a stiffer, less flowable concrete is preferred, such as in structural elements or concrete pavement.

3.5. Compressive Strength

Compressive strength measures a concrete specimen's resistance to crushing. Its primary purpose in testing is to verify that the concrete mixture aligns with design specifications and is suitable for its intended use. The compressive strength results are detailed in Figures 7 and 8.

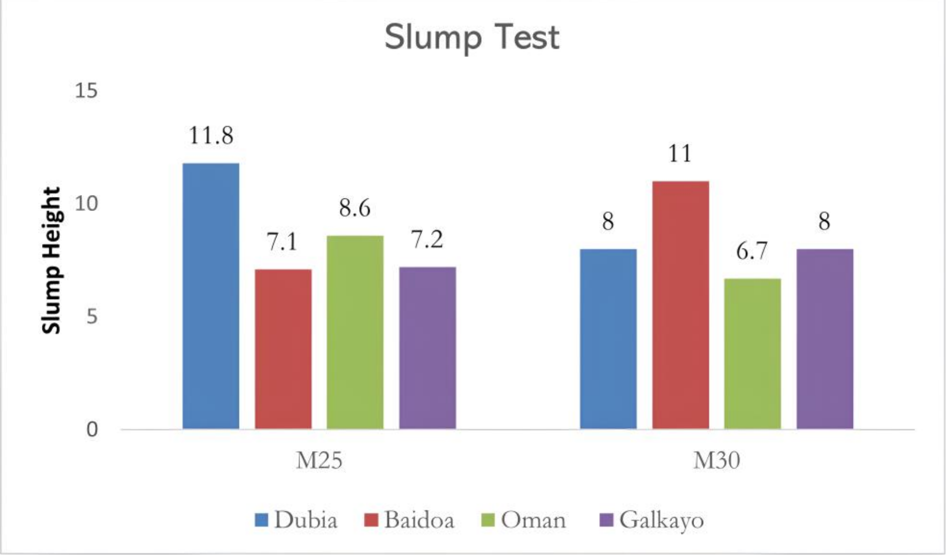

Figure 6. Slump Test Results for M25 and M30 Concrete Mixes

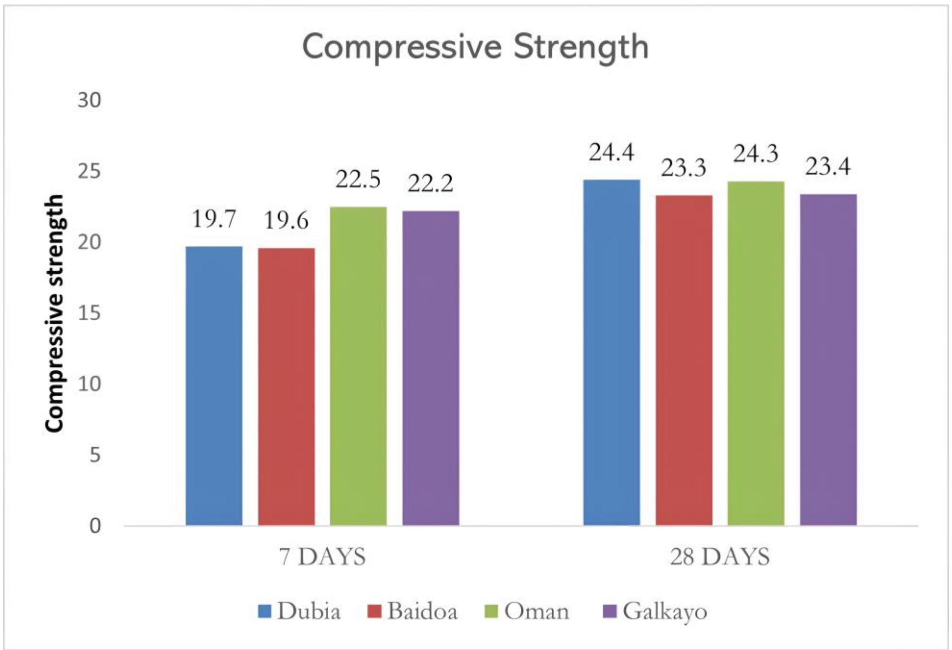

Figure 7. Compressive strength for M25 concrete mix

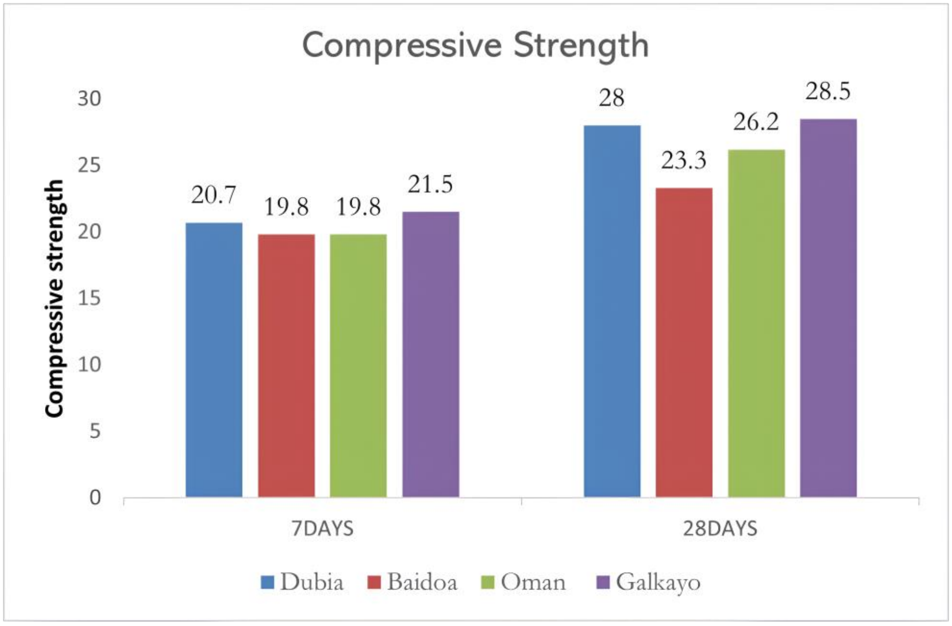

Figure 8. Compressive strength for M25 concrete mix

For the M25 concrete mix, the results showed that the imported aggregate from Oman exhibited the highest 7-day compressive strength of 22.54 MPa, followed by the locally sourced aggregate Galkayo from 22.15 MPa. The locally sourced aggregate from Baidoa had the lowest 7-day compressive strength at 19.63 MPa, while the imported aggregate from Dubai performed moderately with a 7-day strength of 19.68 MPa. At the 28-day mark, Dubai aggregate performed the best, achieving a compressive strength of 24.4 MPa, closely followed by Oman aggregate (24.32 MPa). Galkayo aggregate had a 28-day compressive strength of 23.4 MPa, and Baidoa aggregate had the lowest 28-day compressive strength of 23.26 MPa.

In the case of the M30 concrete mix, Galkayo and Dubai aggregate demonstrated superior long-term performance. At 28 days, the concrete with Galkayo aggregate reached a compressive strength of 28.5 MPa, while the Dubai aggregate achieved 28 MPa. Oman aggregate and Baidoa aggregate had lower 28-day compressive strengths of 26.15 MPa and 23.3 MPa, respectively. However, the early-age (7-day) compressive strengths were more uniform, ranging from 19.78 MPa for the Baidoa and Oman aggregates, Galkayo aggregate reached a compressive strength of 21.5 MPa, while Dubai aggregate achieved 20.67 MPa.

The variations in compressive strength observed in this study can be attributed to the differences in the physical and chemical properties of the aggregates from the different sources, as well as the influence of local sourcing versus imported aggregates.

The 7-day compressive strength results show that the aggregates from Oman and Galkayo exhibited higher early strength development compared to the aggregates from Baidoa and Dubai. This can be important for construction projects that require rapid strength gain, such as precast concrete elements or concrete repairs. One such scenario is concrete repairs and overlays. Rapid strength development is important for concrete used in patching potholes, resurfacing bridge decks, or laying new concrete toppings. Quick strength gain allows the repaired or overlaid areas to be put back into service as soon as possible, minimizing disruption to traffic or operations. Concrete pavements and highways also require rapid strength development. This is crucial for the construction and repair of roads, highways, and airport runways. Quick strength gain enables the newly placed concrete to be opened to traffic more quickly, reducing the impact on transportation and minimizing disruptions. Similarly, industrial and commercial facilities, such as warehouses, manufacturing plants, and retail spaces, often require concrete floors that can support heavy loads and equipment quickly. Rapid strength development in the concrete allows these floors to be put into service more efficiently, enabling the facility to become operational sooner.

There are also specialized applications where rapid strength development in concrete is essential. This includes the construction of dams, nuclear power plants, or offshore oil platforms, where the concrete needs to attain a minimum strength within a short timeframe to ensure the integrity and stability of the structure.

The 28-day compressive strength results indicate that the aggregates from Galkayo and Dubai performed the best, achieving the highest compressive strengths for both the M25 and M30 mix designs. This suggests that these aggregates may be more suitable for applications that require high long-term concrete strength, such as structural elements or heavily loaded foundations. The need for long-term concrete strength is driven by several factors such as Durability, Safety factors, and Service life. These factors are critical in ensuring the integrity and reliability of concrete structures over their intended lifespan.

4. Conclusions

This study provides a comparative analysis of the effects of imported and locally sourced aggregates on the physical and mechanical properties of concrete in Somalia. The results highlight significant differences in performance among the four aggregate types. Galkayo and Dubai aggregates demonstrated superior compressive strength, making them suitable for high-strength structural applications. The Los Angeles abrasion and water absorption tests confirmed that Dubai and Galkayo aggregates exhibited better durability characteristics, while Baidoa aggregates had the highest water absorption, which may affect long-term performance and workability.

The study underscores the need for more rigorous testing and evaluation of local aggregates to establish their viability as a cost-effective alternative to imported materials. Given Somalia's reliance on imported construction materials, encouraging the use of high-quality local aggregates can significantly reduce construction costs and promote sustainable development. Future research should focus on long-term durability assessments, microstructural analysis using SEM, and economic feasibility studies to further understand the implications of using local versus imported aggregates. These findings provide essential insights for engineers, construction companies, and policymakers in making informed decisions about aggregate selection and optimizing concrete mix designs for infrastructure development in Somalia.

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