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Research Article

Effect of Different Sizes of Aggregate on Concrete Strength, Permeability, and Deformation

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Abstract

This study investigates the impact of aggregate size on key concrete properties, including compressive strength, permeability, and deformation behavior. By examining a range of aggregate gradations, the research evaluates how varying particle sizes influence the overall performance of concrete. Experimental analysis reveals that aggregate size plays a crucial role in determining compressive strength, with finer aggregates generally enhancing strength but reducing permeability. Conversely, larger aggregates tend to increase permeability while decreasing resistance to deformation. The study also identifies an optimal balance in aggregate grading that improves both strength and durability. These findings offer valuable insights for optimizing concrete mix design, enabling tailored applications in structural and infrastructural construction projects. The results contribute to a better understanding of material behavior, aiding engineers and designers in selecting appropriate aggregate sizes to meet specific performance criteria. This research underscores the importance of aggregate gradation in achieving the desired concrete performance.

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KEYWORDS: Aggregate Size, Concrete Properties, Compressive Strength, Permeability, Deformation, Mix Design.

1. INTRODUCTION

Concrete is one of the most widely used construction materials globally due to its versatility, strength, and durability. It is composed primarily of cement, water, aggregates, and, in some cases, admixtures that enhance specific properties. Among these components, aggregates form the bulk of the concrete mixture by volume and play a vital role in influencing its overall performance. Aggregates not only contribute to the strength and stability of concrete but also impact its workability, permeability, and long-term durability. The size and gradation of aggregates can significantly affect the concrete's mechanical behavior and resistance to environmental factors. While finer aggregates may improve packing density and compressive strength, coarser aggregates often lead to better load distribution but may increase

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permeability and potential for deformation. Therefore, understanding the influence of aggregate size is essential for designing concrete mixes that meet the specific requirements of different structural applications. This study focuses on investigating the effects of varying aggregate sizes on three fundamental properties of concrete: compressive strength, permeability, and deformation underload. The research aims to evaluate how changes in aggregate size alter these characteristics and to identify optimal aggregate gradations for enhanced performance. The primary objectives include assessing the relationship between aggregate size and concrete strength, analyzing the permeability behavior of concrete with different aggregate sizes, and studying the deformation properties under applied loads. The outcomes of this study are intended to provide practical insights for engineers and construction professionals in optimizing concrete mix designs for improved structural efficiency and durability.

2. MATERIALS AND METHODS

This study investigates the influence of aggregate size on the mechanical and durability properties of concrete through carefully controlled experimental procedures. The materials used, mix proportions, and testing methods are described below in detail.

Materials

The concrete mix was composed of the following materials:
Cement: Ordinary Portland Cement (OPC) was used as the binding material.
Aggregates: Both fine and coarse aggregates were utilized. The coarse aggregates were classified into three distinct size categories 10 mm (small), 12 mm (medium), and 20 mm (large)—to study the effect of particle size.
Water: Clean, potable water was used for mixing and curing to ensure consistency and avoid contamination.

Aggregate Sizes

Three aggregate size categories were selected to evaluate their impact on concrete performance:

- 10 mm (small-sized aggregate)
- 12 mm (medium-sized aggregate)
- 20 mm (large-sized aggregate)

Mix Proportions

Concrete samples were prepared using a standardized mix design with a fixed water-cement (w/c) ratio of 0.45 to maintain uniformity across all tests. For each aggregate size, three sets of concrete samples were cast, ensuring replication and accuracy in test results.

Testing Methods

Compressive Strength: Concrete cubes were tested on 7, 14, and 28 days using a Universal Testing Machine (UTM) to assess strength development over time.
Permeability: The permeability of each sample was measured using a constant head permeability apparatus to evaluate resistance to fluid penetration.
Deformation: Strain gauges were attached to concrete specimens to record deformation under compressive loading, providing insights into the elastic and inelastic behavior of the material.
These methods provided comprehensive data on the influence of aggregate size on concrete properties.

3. RESULTS AND DISCUSSION

This section presents a detailed analysis of the experimental findings, focusing on how aggregate size influences the compressive strength of concrete. The results demonstrate that aggregate size plays a significant role in determining the mechanical performance of concrete, particularly its strength.

Effect on Compressive Strength

The compressive strength of concrete samples with different aggregate sizes was measured at 28 days. The results are summarized in the table below:

Table 1: Compressive Strength of Concrete at 28 Days for Different Aggregate Sizes

Aggregate Size	Compressive Strength (MPa) at 28 Days
10 mm	34.2 MPa
12 mm	38.5 MPa
20 mm	35.8 MPa

Among the three aggregate sizes tested, concrete made with 12 mm aggregates achieved the highest compressive strength of 38.5 MPa at 28 days. This improved strength is attributed to better particle packing, which reduces internal voids, and stronger interfacial transition zones between the aggregate and cement paste. The medium-sized aggregates strike an optimal balance between the surface area and interlocking capacity, leading to a denser and more cohesive concrete matrix. Concrete with 10 mm aggregates exhibited the lowest strength (34.2 MPa). The increased surface area of smaller aggregates leads to higher water demand, which can negatively affect the water-cement ratio and result in weaker bonding within the concrete structure. On the other hand, concrete with 20 mm aggregates showed a slightly higher strength than the 10 mm samples (35.8 MPa) but was still lower than the 12 mm mix. This is likely due to larger voids and reduced paste-aggregate bonding, which compromise the matrix cohesion and reduce overall strength. These findings emphasize the importance of selecting an appropriate aggregate size in concrete mix design to optimize strength performance.

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Compressive Strength vs Aggregate Size

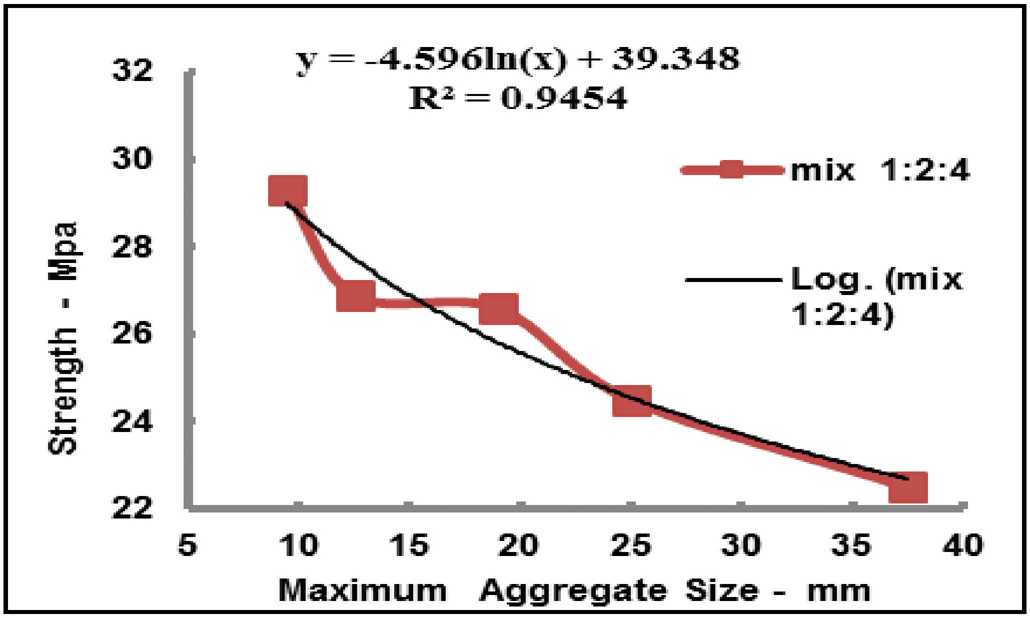

Fig 1: Relationship between aggregate size and compressive strength

Effect on Permeability

Permeability is a critical property that determines the durability and resistance of concrete to the ingress of water, chemicals, and other harmful substances. It is largely influenced by the internal pore structure, which in turn is affected by the size and distribution of aggregates. In this study, the permeability of concrete samples prepared with three different aggregate sizes—10 mm, 12 mm, and 20 mm—was measured using the constant head method. The results are presented in the table below:

Table 2: Permeability of Concrete for Different Aggregate Sizes

Aggregate Size	Permeability (cm/s)
10 mm	1.1×10^{-6}
12 mm	8.3×10^{-7}
20 mm	2.2×10^{-6}

The results clearly show that concrete with 20 mm aggregates had the highest permeability at 2.2×10^{-6} cm/s. This is attributed to the larger aggregate size creating more voids and reducing the overall packing density. The increased void content leads to a more porous matrix, allowing water and other substances to penetrate more easily. Additionally, the larger aggregates may hinder uniform compaction, further increasing permeability. Conversely, concrete containing 12 mm aggregates exhibited the lowest permeability at 8.3×10^{-7} cm/s. The 12 mm aggregate size appears to provide an optimal balance between particle size and packing efficiency. The result is denser concrete with fewer interconnected voids, leading to reduced permeability. Improved interfacial bonding and better distribution of the cement paste also contribute to minimizing pore connectivity. Concrete with 10 mm aggregates showed a moderate permeability of 1.1×10^{-6} cm/s. While smaller aggregates can help fill voids due to their high surface area and improved paste coverage, they also require more water, potentially resulting in higher porosity if not properly controlled. However, the increased paste content can fill smaller voids effectively, resulting in relatively lower permeability compared to the 20 mm mix. These findings highlight that aggregate size has a direct and significant influence on the permeability of concrete. Choosing the right aggregate size can help reduce permeability and enhance the durability of concrete structures, especially in environments exposed to water or aggressive chemicals.

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Permeability vs Aggregate Size

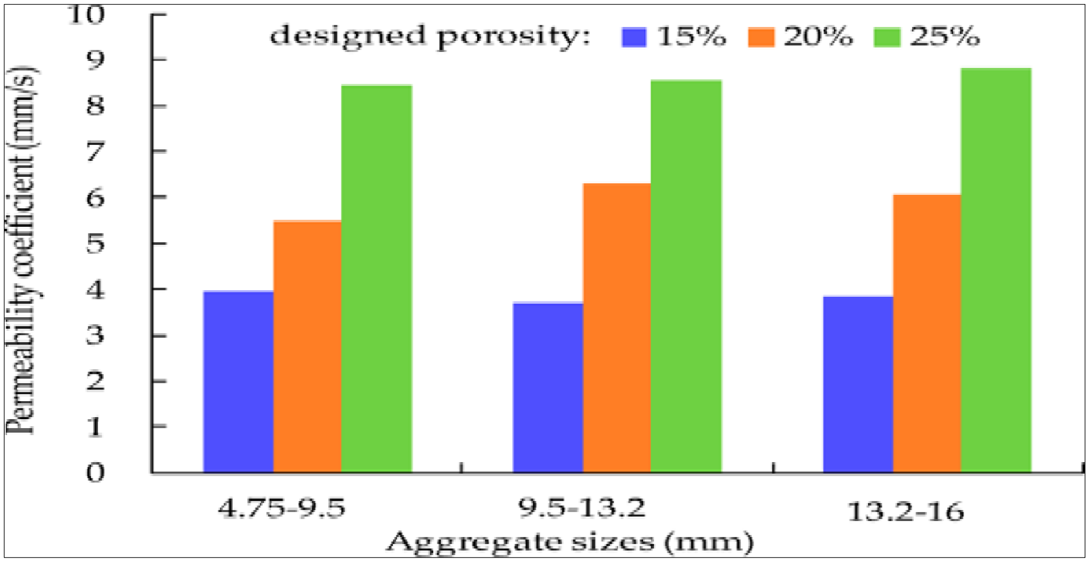

Fig 2: Permeability variation with aggregate size

Effect on Deformation

Deformation underload is a vital parameter that reflects a concrete specimen's ability to withstand stress without failure. It directly relates to the material's stiffness, ductility, and structural behavior under compressive loading. In this study, deformation was measured using strain gauges attached to concrete specimens, and the results for different aggregate sizes are summarized below:

Table 3: Deformation Under Load for Different Aggregate Sizes

Aggregate Size	Deformation Under Load (mm)
10 mm	0.42 mm
12 mm	0.37 mm
20 mm	0.49 mm

The results reveal that concrete with 20 mm aggregates exhibited the highest deformation under compressive load, with a value of 0.49 mm. This behavior indicates a more brittle response, where the larger aggregates create internal stress concentrations and less homogeneous stress distribution. The increased void content and weaker paste-aggregate bonding typically associated with larger aggregates contribute to reduced energy absorption and less capacity for uniform strain distribution, making the concrete more susceptible to cracking under load. In contrast, concrete made with 12 mm aggregates showed the least deformation at 0.37 mm, suggesting higher stiffness and better structural performance. The intermediate size of the aggregates likely promotes more efficient stress transfer across the matrix, reducing strain underload. The improved interlocking and packing density results in a more uniform and cohesive structure, enhancing both strength and ductility. This balance makes 12 mm aggregate concrete ideal for applications where moderate flexibility and high strength are required. Concrete with 10 mm aggregates demonstrated a moderate deformation of 0.42 mm, indicating more uniform strain distribution but lower stiffness compared to the 12 mm mix. The higher surface area of smaller aggregates increases paste demand, which can create a softer matrix. While this may help in spreading deformation more evenly, it also results in reduced rigidity, making the concrete less suitable for load-bearing elements where minimal deflection is critical. Overall, the results indicate that aggregate size significantly affects concrete deformation characteristics. While larger aggregates increase brittleness and reduce ductility, smaller aggregates allow for more even deformation but may compromise stiffness. The 12 mm aggregates offer the best balance, ensuring good stress distribution, moderate flexibility, and enhanced structural performance.

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Deformation vs Aggregate Size

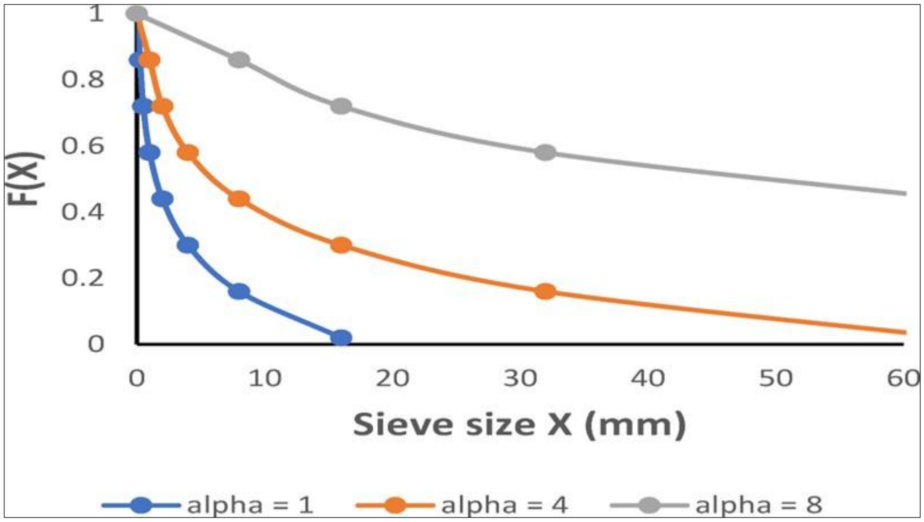

Fig 3: Deformation behavior with different aggregate sizes

4. DISCUSSION

The experimental results clearly demonstrate that aggregate size significantly influences the key performance characteristics of concrete, namely compressive strength, permeability, and deformation. Among the three aggregate sizes tested (10 mm, 12 mm, and 20 mm), 12 mm aggregates consistently provided the most balanced performance, making them the optimal choice for a wide range of structural applications. In terms of compressive strength, concrete containing 12 mm aggregates achieved the highest value. This superior performance can be attributed to better particle interlocking, which minimizes the formation of weak zones within the concrete matrix. The intermediate size of the aggregates promotes a denser packing structure and enhances the bonding between the cement paste and the aggregate surfaces. As a result, the material exhibits improved load-carrying capacity and resistance to cracking. Regarding permeability, the 12 mm aggregate mix again outperformed the others by exhibiting the lowest permeability. This is due to the balanced distribution of fine and coarse particles, which leads to an optimized pore structure with fewer interconnected voids. A denser and more cohesive internal structure prevents the easy passage of water and other aggressive agents, thus improving the durability of the concrete. When evaluating deformation behavior, the 12 mm aggregate concrete displayed the least deformation under compressive loading, indicating better stiffness and efficient stress distribution. This ability to distribute loads more uniformly reduces the risk of sudden failure and makes the structure more reliable under long-term service conditions. These results highlight the importance of aggregate gradation in concrete mix design. Selecting an appropriate aggregate size is not just a matter of material availability but a critical decision that impacts the mechanical performance, durability, and service life of the structure. While 12 mm aggregates are recommended for load-bearing and structural elements due to their optimal performance, larger aggregates such as 20 mm may be more suitable for non-structural applications or where higher permeability is acceptable or even beneficial, such as in drainage layers or pervious concrete. In conclusion, achieving a well-graded and balanced mix is key to producing concrete with high performance across multiple criteria. This study reinforces the need to tailor aggregate selection to the specific functional demands of the concrete application.

5. CONCLUSION

This study demonstrates that aggregate size plays a crucial role in influencing the mechanical and durability properties of concrete, particularly in terms of compressive strength, permeability, and deformation behavior. Through a series of controlled experiments, it was found that 12 mm aggregates consistently delivered the most favorable results across all performance parameters. Concrete prepared with 12 mm aggregates exhibited the highest compressive strength, owing to enhanced particle interlocking and improved bonding within the cement matrix. In addition, this mix showed the lowest permeability, which indicates a denser internal structure with minimal voids, contributing to improved durability and resistance to environmental degradation. Furthermore, concrete with 12 mm aggregates displayed minimal deformation under load, suggesting better stiffness and effective stress distribution—critical factors for structural integrity and long-term performance. In contrast, larger aggregates (20 mm) were associated with increased permeability and greater deformation, which can compromise structural efficiency. Similarly, while smaller aggregates (10 mm) showed better paste coverage, they demanded more water and resulted in lower strength and moderate permeability. Based on these observations, 12 mm aggregate size is recommended for structural applications, such as beams, columns, slabs, and load-bearing elements, where high strength and durability are essential. Larger aggregates may still

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be suitable in specific scenarios, such as pervious concrete or mass concrete where permeability is less critical or even desirable. Overall, this study emphasizes the importance of careful aggregate selection in concrete mix design to achieve the desired balance of strength, durability, and performance in diverse construction scenarios.

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Pankaj Singh is currently pursuing a Bachelor of Technology in Civil Engineering from Amity University, Uttar Pradesh, Lucknow campus. He completed his 12th from St. Xavier's School and his 10th from SOS Hermann Gmeiner School, both located in Varanasi, where he also completed his entire schooling. Pankaj is a dedicated student, working hard towards building a successful future.

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