


Pervious Concrete: Improving Design for Optimal Balance between Strength, Permeability and Sustainability

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Abstract

This study aims to optimize the design of pervious concrete by investigating the effects of aggregate shapes and different fine aggregate percentages on the properties of pervious concrete. Pervious concrete offers numerous sustainable environmental benefits mostly including reduction of storm water runoff, recharging of groundwater, skid resistance enhancement of pavement surface and traffic noise reduction. The main objective of this study was to achieve an optimum balance between two critical parameters (compressive strength and porosity) by analyzing various angularity numbers, flakiness and elongation indices and percentages of fine aggregate. Compressive strength test revealed that 8% fine aggregate pervious concrete samples performed optimally providing a balanced combination of strength and permeability. The results further revealed that lower fine aggregate content showed excellent porosity but significantly lower strength whereas higher fine aggregate content showed increased compressive strength but reduced permeability. Further analysis of aggregate types revealed that normal coarse aggregates (angularity number 6.9) provided a favourable balance between compressive strength and permeability. The results further showed that high angularity coarse aggregates resulted in improved strength but with slightly reduced porosity while as rounded aggregates provided better porosity but reduced strength due to their smoother surfaces and reduced interparticle bonding. Flaky aggregates negatively affected both strength and porosity due to weaker particle bonding and poor mutual bonding. Therefore, the best performing mix was identified as the mix with 8% fine aggregate content and normal coarse aggregate (angularity number 6.9) providing a favourable balance between compressive strength for structural applications and porosity for water infiltration with compressive strength of 27.5 MPa and permeability of 1.11 mm/s after 28 days of curing.

Keywords: Fine aggregate content, Coarse aggregate angularity, Compressive strength, Permeability, Structural integrity, Hydraulic conductivity.

1. Introduction

Concrete, the most commonly used composite material having a low tensile strength but a relatively high compressive strength is made up of cement, water, fine and coarse particles (Kim et al. 2019; Hache et al. 2020; Meti et al. 2020). It is anticipated that the global annual usage of concrete is around 10 billion tons (Hache et al. 2020; Marandi and Shirzad 2025). It is an amazing impermeable construction material that works in almost every environment and can be moulded into any shape (Shelton and Harper 1982; Ali 2024). However, the emergence of new phenomena such as climate change and global warming has caused numerous predicaments in various domains including long-term droughts, depletion of subterranean water resources, desertification, devastation of agricultural soils, river desiccation, land subsidence, escalation of urban heat island effect and sudden floods (Chen et al. 2019a; Elsaidy et al. 2025). Therefore, a sustainable modification to conventional concrete is required to address such issues.

Recently, pervious concrete has become progressively more attractive for use in urban permeable pavement systems (AlShareedah 2001). The use of pervious concrete for sustainable construction activities continues to rise in the construction industry (AlShareedah 2001). Pervious concrete offers a variety of advantages including reduction of storm water runoff and recharging of groundwater when used as a paving material for parking lots, low volume pavements and sidewalks (AlShareedah 2001; ACI Committee 2010; Abdel-Aziz et al. 2015). Pervious concrete has recently emerged as a solution to the heat-island problem (Kevern 2015; Kabagire and Yahia 2016; Chen et al. 2019a). Compared to the impermeable concrete pavement, the pervious concrete exhibits relatively lower surface temperatures (ACI Committee 2010; Li et al. 2013; Tushar Ali and Harunur Rashid 2023). Furthermore, pervious concrete has been found to be effective in reducing traffic noise (Bonicelli and Pianeta 2019; Pranoto et al. 2023). Permeable concrete had noise levels between 96 and 98 dBA while traditional concrete noise levels ranged between 100 and 110 dBA (Pranoto et al. 2023). Moreover, it has been found that pervious concrete has better skid resistance than impermeable concrete (Iii et al. 2001; Kováč and Sičáková 2018). Pervious Concrete was first used in 1852 (ACI Committee 2010; Leminy and Akers). It has been employed in European countries since the nineteenth century (Young Min Joung 2008; ACI Committee 2010). The earliest usage of pervious concrete in modern history was for two houses in England. Over 900 houses were built by 1942 (Young Min Joung 2008; ACI Committee 2010). Prior to World War II, pervious concrete was only used for two-storey homes. However, it was used for an even wider range of activities after 1946. It was designated as a material for load-bearing components in structures up to 10 stories high (ACI

Committee 2010). Pervious concrete consists of a carefully controlled amount of paste and an aggregate system with a uniform particle size or a narrow particle size distribution and with little or no sand (ACI Committee 2010; Kabagire and Yahia 2016). The paste in pervious concrete creates a thick layer around the aggregate particles binding them together while a significant portion (15-25%) of interconnected macro-voids persists in the concrete. Therefore, pervious concrete is very permeable with a water flow rate of about 0.34 cm/s (480 in/h) (Chen et al. 2013). The infiltration rate of pervious concrete will vary with aggregate size and density of the mixture will range from 80 to 720 liters per minute per square meter (Pratap et al. 2017). The permeability of a pervious concrete pavement system with moderate porosity is usually 143 litres per minute per square metre (Obla 2010; K Sreenath Reddy). On the other hand, the soil's steady state infiltration rate varies between 25 and 0.25 mm per hour (Azam Ahmad 2024; K Sreenath Reddy). Water can effectively move through pervious concrete with associated pores that vary from 0.08 to 0.32 inches (2-3mm). Also with typical compressive strengths of 2.8 MPa to 28 MPa, a void content can vary from 15 to 35% (Elango et al. 2021). It is recommended to maintain w/c ratio between 0.26 and 0.45 in order to create effective pervious concrete with an excellent aggregate coating and paste stability. A single sized coarse aggregate or grading between 19 and 9.5 mm can be used to maintain a suitable void content in the concrete (ACI Committee 2010; Aliabdo et al. 2018; Elango et al. 2021). Moreover, it has been observed that reduced void content results in increased compressive strength (Joshi 2016; Elango et al. 2021). Additionally, the void content of pervious concrete is determined by a number of parameters including aggregate gradation, cementitious material content and compaction effort (Elango et al. 2021). Pervious concrete typically has a flexural strength of between 1 MPa and 3.8 MPa (Radlińska et al. 2012; Aliabdo et al. 2018).

Although previous studies have investigated different aggregate sizes, mixing ratios and inclusion of additives such as fly ash, polypropylene and nano silica, there is still no consensus on the optimal mix design that balances permeability, strength and durability which are important for practical application of pervious concrete. Further exploration into the long-term durability of pervious concrete is also necessary. Furthermore, previous studies have primarily focused on short-term results such as compressive strength and permeability after 28 days of curing but there is insufficient data on how the material behaves under prolonged exposure to environmental factors like freezing, thawing and clogging. Although some studies pointed out that clogging due to clayey materials significantly affects permeability over time but solutions for maintaining permeability such as cleaning techniques require further validation in real world conditions.

The present study was aimed at assessing the performance characteristics of pervious concrete in comparison to conventional (normal) concrete and optimizing the mix design for achieving the best balance between strength, permeability and sustainability. To accomplish this, a systematic methodology was developed incorporating a detailed literature review, laboratory testing and data analysis to ensure a comprehensive understanding of the subject. The study was done on various

parameters such as compressive strength, porosity, angularity, flakiness and elongation indices of coarse aggregates and varied percentages of fine aggregate which are critical in determining the structural integrity and permeability of pervious concrete.

2. Materials and Methodology

2.1.1 Aggregates

Coarse aggregates and fine aggregates were used for the present investigation. Some laboratory tests were conducted on coarse and fine aggregate samples as per IS (Indian Standard) codal provisions to determine the physical properties such as particle size distribution and specific gravity of the aggregates. **Fig. 1** shows sieve sets used to perform sieve analysis of the aggregates and **Fig. 2** shows pycnometer apparatus used to determine specific gravity of the aggregates. Additionally, angularity number, flakiness and elongation indices were calculated for coarse aggregates in order to ensure suitability for concrete mixes. **Fig. 3** shows flakiness and elongation index test performed on coarse aggregates. The results of laboratory tests performed on fine aggregates are shown in table 1. The flakiness and elongation indices test results of coarse aggregates are shown in table 2. Also, specific gravity and angularity test results of coarse aggregates are shown in table 3.



Fig. 1 Sieve sets used to perform sieve analysis of the aggregates



Fig. 2 Pycnometer apparatus used to determine specific gravity of the aggregates

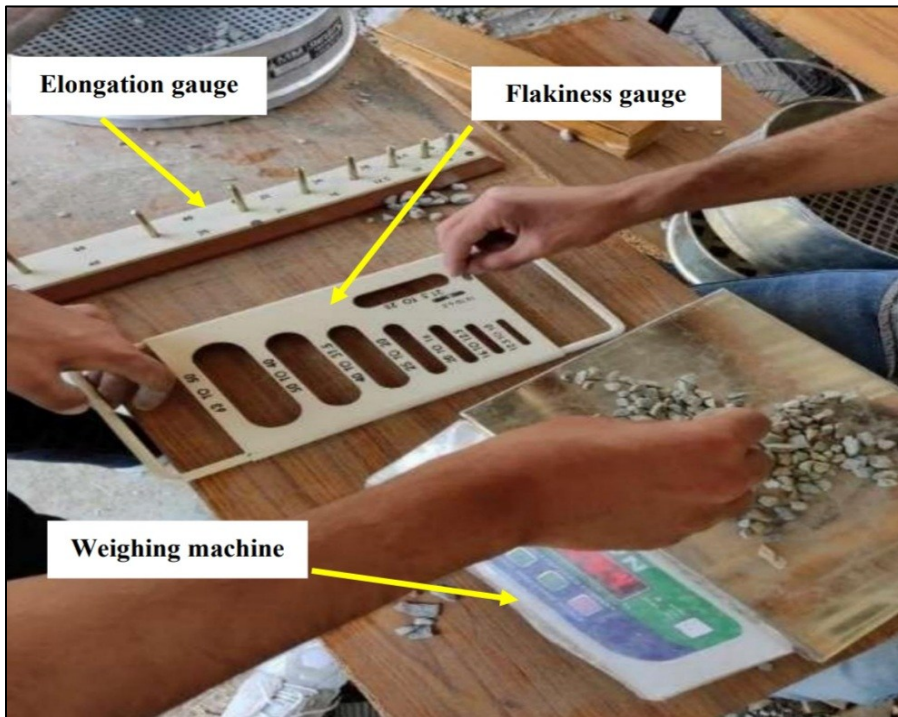


Fig. 3 Flakiness and elongation index test performed on coarse aggregates

Table 1

Laboratory test results of fine aggregate

Description	Values
Grade (or zone)	Zone 3
Specific gravity	2.64

Table 2

Flakiness and elongation index test results of coarse aggregates

Description	Values
Flakiness Index	9.65 %
Elongation Index	10.15 %

Table 3

Specific gravity and angularity test results of coarse aggregates

Aggregate type (or shape)	Angularity number	Specific gravity
Rounded	2.3	2.78
Normal (sub- angular)	6.9	2.78
Angular (highly angular)	9.9	2.78

2.1.2 Cement

Ordinary Portland cement (OPC) of grade 43 was used as a cementitious material for the present study which was brought from a local supplier in Budgam, Kashmir. Certain laboratory tests were performed on the cement sample to determine the specific gravity, consistency and initial and final setting time of cement. **Fig. 4** shows vicat apparatus used to measure consistency of the cement. The laboratory results Ordinary Portland Cement of grade 43 (including standard consistency, initial and final setting time, and specific gravity of the selected cement) are shown in table 4.

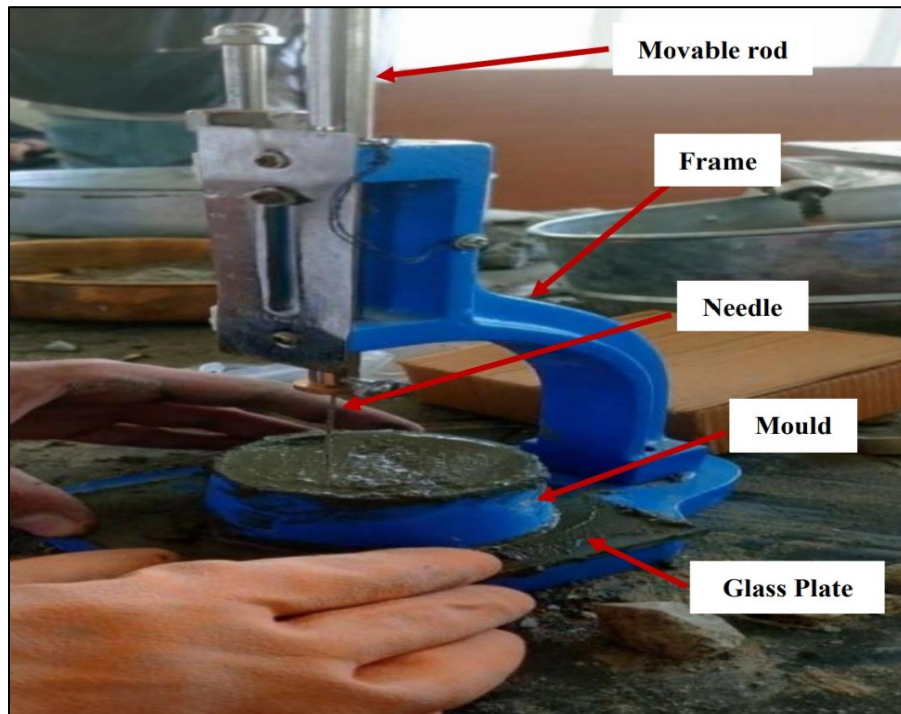


Fig. 4 Vicat apparatus used to measure consistency of the cement

Table 4
Laboratory test results of Ordinary Portland Cement of grade 43

Description	Values
Standard consistency	30 %
Initial setting time	42 minutes
Final setting time	480 minutes
Specific gravity	3.1

2.1.3 Water

Tap water with a pH of 7 was used for the present study. Also it was ensured that no organic or inorganic contaminants were present in the water used to mix concrete.

2.1.4 Admixtures

A polycarboxylate ether-based superplasticizer with a specific gravity of 1.21 was added to improve workability of concrete.

2.2 Methodology

2.2.1 Mixing proportions

For the present investigation, coarse aggregates of sizes ranging from 4.75 mm to 12 mm with specific gravity of 2.78 were used which were sieved on different sieve sets as shown in **Fig. 1**. Usually the specific gravity of coarse aggregates ranges

from 2.6 to 2.9 (Abas et al. 2015; Tadesse Abegaz et al. 2020). Three types of coarse aggregates were used for the present study based on the angularity number including rounded (angularity number 2.3), normal (angularity number 6.9) and highly angular (angularity number 9.9). The angularity number of coarse aggregates typically ranges from 0 to 11 (Rahimi and Muniandy 2016). Fine aggregates of zone 3 with specific gravity of 2.64 were incorporated. The specific gravity ranges from 2.5 to 2.9 for fine aggregates (Odeyemi et al. 2019; Algoni et al. 2024). OPC of grade 43 was used with specific gravity of 3.1 and consistency of 30%. Water-cement ratio was calculated and set at 0.35 ensuring an optimal balance between strength and durability. Polycarboxylate ether-based superplasticizer with specific gravity of 1.21 was also added to improve workability of concrete. All these values are in accordance with the ASTM (American Society for Testing and Materials) and IS (Indian Standards) codes.

2.2.2 Sample preparation

In the present investigation, moulds of size 150 mm x 150 mm x 150 mm were used for casting the concrete samples. The moulds were thoroughly oiled using mobil oil to ensure easy demoulding after the concrete sets (Abdul'aziz and Abubakar 23AD; Okezue et al. 2020). The target was to create M40 grade of concrete samples. The concrete samples were manufactured in two series (series A and series B). Series A included normal or conventional concrete samples. Three batches of samples were created in series A with different ratios of cement to fine to coarse aggregates (Batch A₁ for ratio of 1:1.38:2.5, Batch A₂ for ratio of 1:1.59:2.6 and Batch A₃ for ratio of 1:1:2). The pre-defined concrete mix materials were mixed thoroughly using a mechanical mixer to ensure uniform distribution of aggregates and proper coating of cement paste over the particles (Okezue et al. 2020). After the concrete mix was prepared, it was poured into the prepared moulds in layers. Each layer was compacted by tamping 25 times using a 16 mm diameter and 0.6 m long tamping rod ensuring adequate compaction (Abdul'aziz and Abubakar 23AD; Okezue et al. 2020). Once filled, the concrete in the moulds was left undisturbed for 24 hours in a vibration-free area. The samples were demoulded after 24 hours and submerged in curing tank with clean, fresh water for curing at a standard temperature of $27 \pm 2^\circ \text{C}$ till the time of testing as proper curing is essential to enhance the strength and durability of concrete (Okezue et al. 2020; of Indian Standards). Series B included nine batches of pervious concrete samples. Batches B₁, B₂ and B₃ included the pervious concrete samples with normal aggregates (angularity number 6.9) with different percentages of fine aggregate (0% fines for B₁, 8% fines for B₂ and 15% fines for B₃). Batches B₄, B₅ and B₆ included the pervious concrete samples with higher angularity of aggregates (angularity number 9.9) with different percentages of fine aggregate (0% fines for B₄, 8% fines for B₅ and 15% fines for B₆). Batches B₇, B₈ and B₉ included the pervious concrete samples with rounded aggregates (angularity number 2.3) with different percentages of fine aggregate (0%

finer for B₇, 8% finer for B₈ and 15% finer for B₉). The same manufacturing and curing procedures were applied for series B (pervious concrete samples) which were used for series A (normal concrete samples).

2.3 Experimental evaluation of the properties of cubical concrete specimens

2.3.1 Compressive strength analysis

The cubical concrete samples of series A and B were tested in the automatic compression testing machine (ACTM) as shown in **Fig. 5** to assess and compare the compressive strength results of series A (normal concrete) and series B (pervious concrete) intended to reach M40 compressive strength. Also, the compressive strength of the pervious concrete samples from series B were evaluated for varied percentages of fine aggregate (0%, 8% and 15%) and different angularity numbers (2.3 for rounded aggregates, 6.9 for normal aggregates and 9.9 for highly angular aggregates). This was done to determine the impact of using various proportions of fine aggregates to the total number of aggregates which is used in normal concrete and to determine the effect of different shapes of coarse aggregates which affects the bond between particles and thus the overall performance of pervious concrete and therefore determining an optimum concrete mix which provides a favourable balance between compressive strength and porosity.

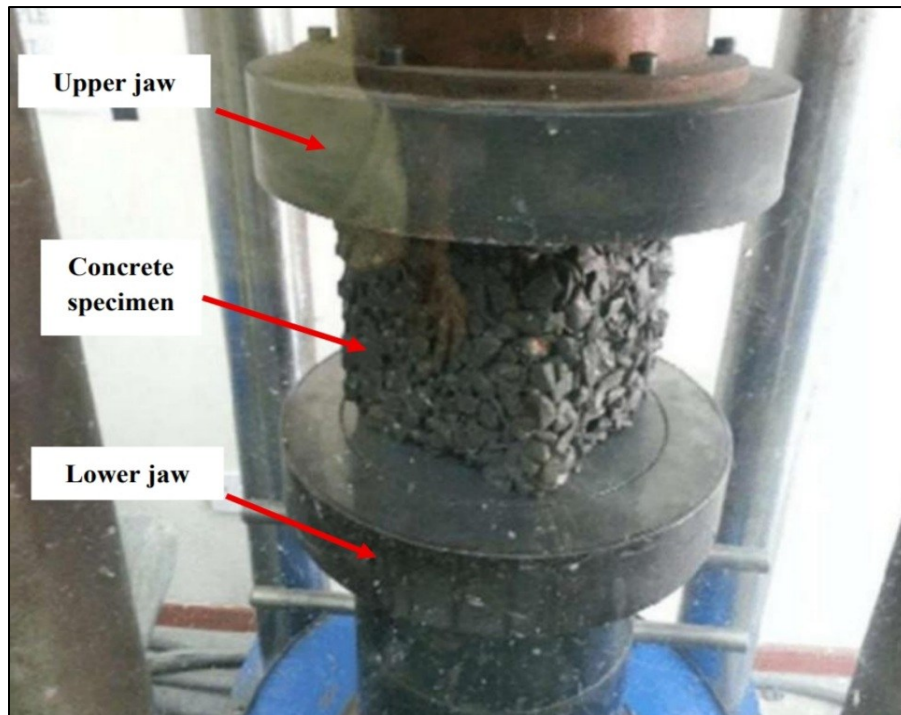


Fig. 5 Pervious concrete specimen under automatic compression testing machine with load capacity of 1000 kN

2.3.2 Permeability analysis

Constant-head permeability test was performed on the pervious concrete cubes from series B as shown in **Fig. 6** which shows placing of pervious concrete cube in permeability apparatus and **Fig. 7** which shows passing of water through the pervious concrete specimen in order to determine permeability (or hydraulic conductivity) of pervious concrete samples (ASTM C1701/C1701M) (Chen et al. 2019b). This test was performed after 28 days of curing of the samples to assess the impact of various proportions of fine aggregate (0%, 8% and 15%) and different shapes of coarse aggregate (rounded and angular aggregates) on the permeability of pervious concrete and therefore to determine an optimum mix which offers a favourable balance between the compressive strength and permeability for pervious concrete.

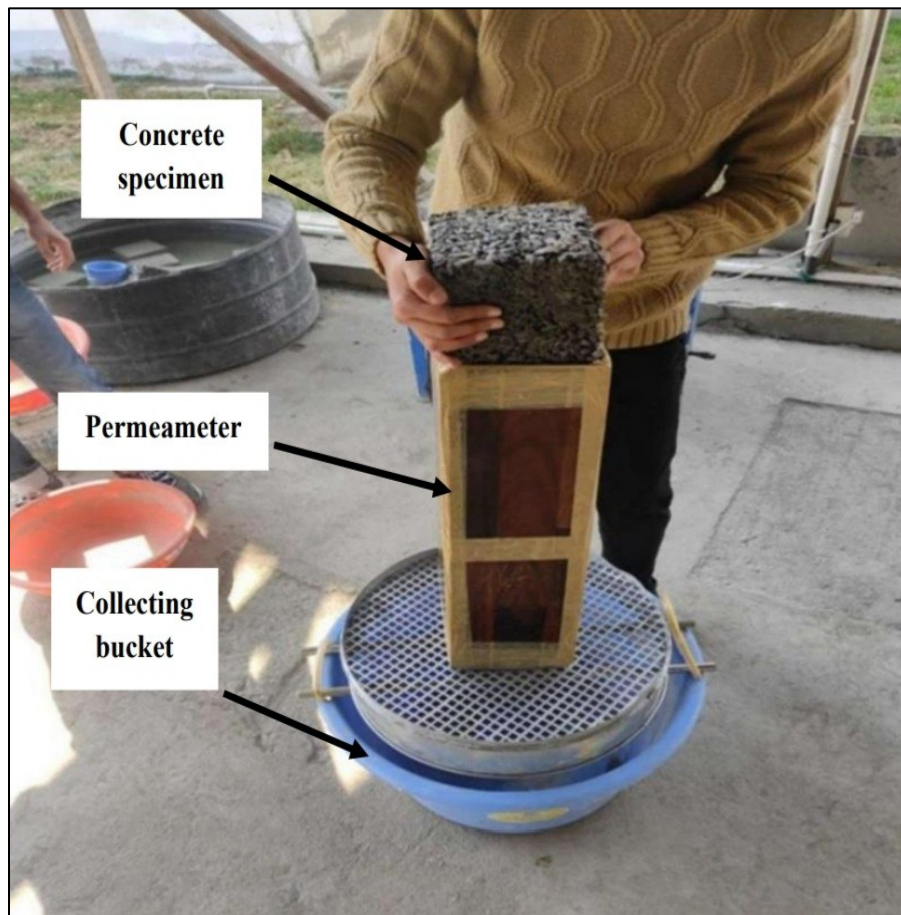


Fig. 6 Placing of pervious concrete cube in the permeability testing apparatus



Fig. 7 Passing of water through the pervious concrete specimen

3. Results and Discussion

In this chapter, results of various laboratory tests performed on the cubical concrete specimens from series A (normal concrete) and series B (pervious concrete) have been listed along with their tabular form, graphs and bar charts.

3.1 Compressive strength test results of normal concrete cubes

The concrete samples from series A were placed in the ACTM (Automatic Compression Testing Machine) and the corresponding compressive strength results for each sample were recorded. These samples were prepared with different proportions of concrete mix. Figures 8 to 10 have shown the average compressive strength values for various proportions of concrete mix after 7, 14 and 28 days of curing. From **Fig. 8** which shows graph of average compressive strength results of batch A₁ normal concrete cubes after 7, 14 and 28 days of curing it can be seen that the average compressive strength values of batch A₁ cubes (having concrete mix ratio of 1:1.38:2.5) after 7, 14 and 28 days of curing were 16.9 MPa, 27.78 MPa and 43 MPa respectively. For batch A₂ (having concrete mix ratio of 1:1.59:2.6), the average compressive strength values of samples after 7, 14 and 28 days of curing were 16.23 MPa, 26.5 MPa and 42 MPa respectively as seen in **Fig. 9** graph of

average compressive strength results of batch A2 normal concrete cubes after 7, 14 ad 28 days of curing and for batch A₃ (having concrete mix ratio of 1:1:2) the average compressive strength values of samples after 7, 14 and 28 days of curing were 14.98 MPa, 23.02 MPa and 36.98 MPa respectively as seen in **Fig. 10** graph of average compressive strength results of batch A₃ normal concrete cubes after 7, 14 ad 28 days of curing. The above results specified that even though the average compressive strength of batch A₂ concrete samples was still strong, but the performance of this mix was comparatively less robust than the mix of batch A₁ concrete samples. The concrete cube samples from batch A₁ delivered impressive results after 7, 14 and 28 days of curing outperforming the samples from other two batches (A₂ and A₃) underlining the critical importance of mix design in optimizing the strength and performance of concrete.

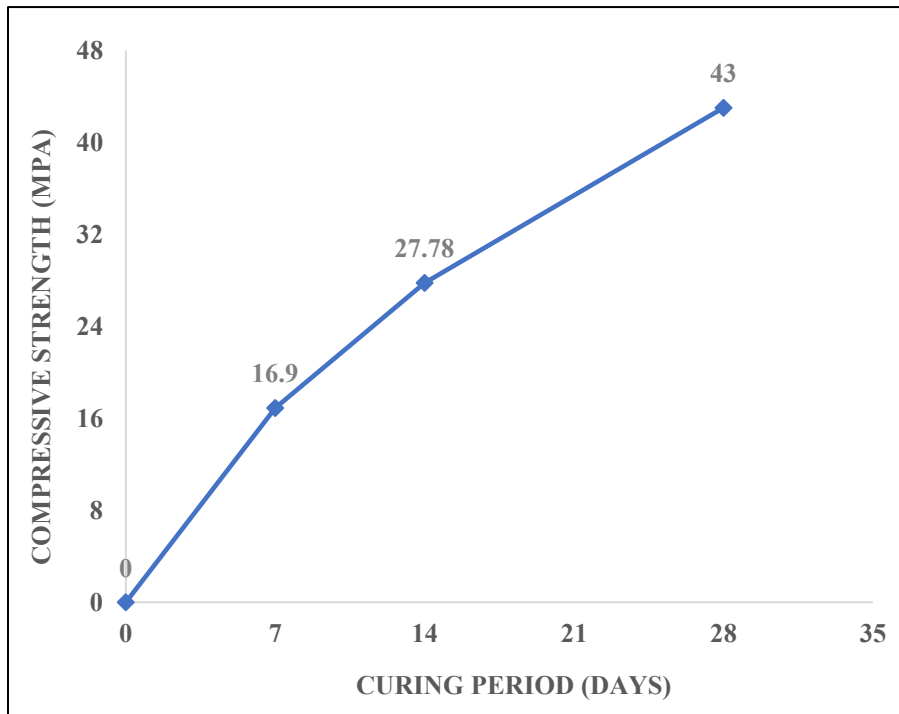


Fig. 8 Graph showing average compressive strength results of batch A₁ Normal concrete cubes after 7, 14 ad 28 days of curing

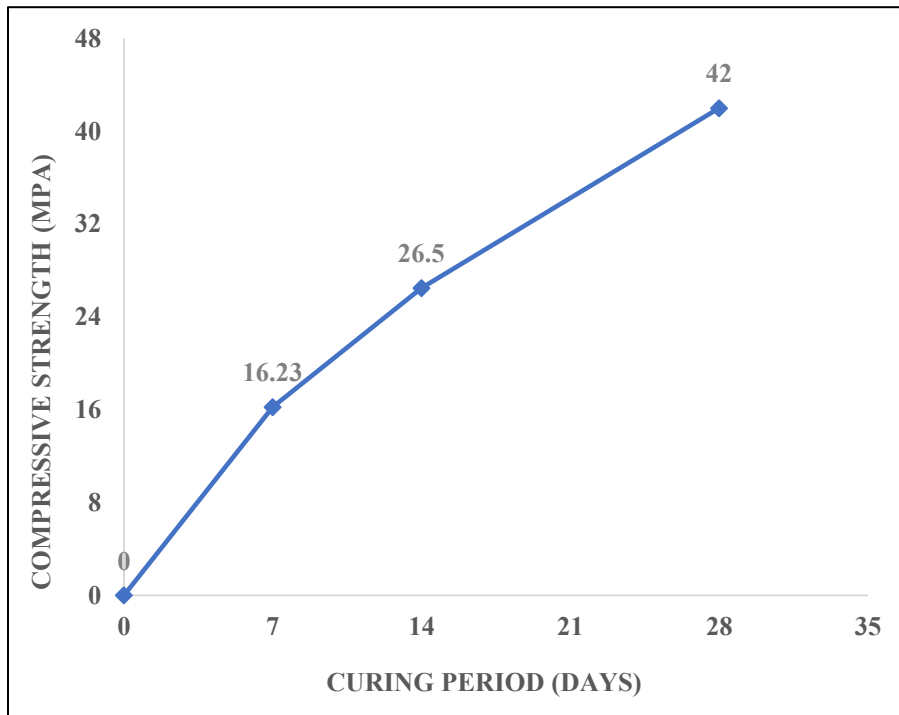


Fig. 9 Graph showing average compressive strength results of batch A₂ Normal concrete cubes after 7, 14 ad 28 days of curing

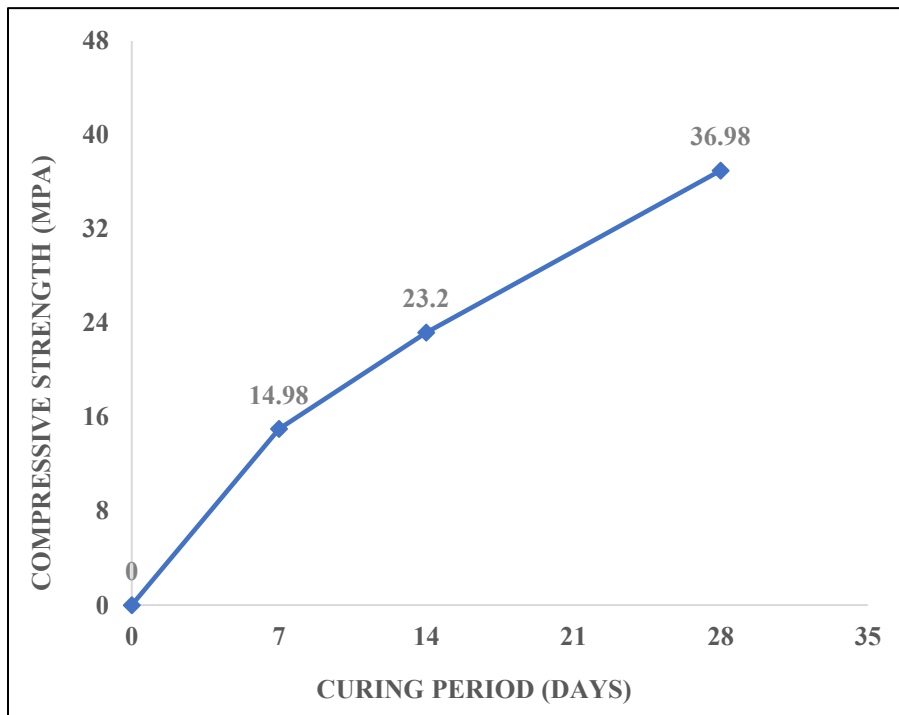


Fig. 10 Graph showing average compressive strength results of batch A₃ Normal concrete cubes after 7, 14 ad 28 days of curing

3.2 Compressive strength test results of pervious concrete cubes

The pervious concrete samples from series B were also placed in the ACTM and the corresponding compressive strength results for each sample were recorded.

3.2.1 Compressive strength test results of pervious concrete cubes with coarse aggregates of angularity number 6.9

Figures 11 to 13 have shown the average compressive strength values for batches B₁, B₂ and B₃ having different percentages of fine aggregate (0% fines for B₁, 8% fines for B₂ and 15% fines for B₃) after 7, 14 and 28 days of curing. It can be seen from **Fig. 11** graph of average compressive strength results of batch B₁ pervious concrete cubes (0%fines) after 7, 14 ad 28 days of curing that the average compressive strength values of batch B₁ samples (having normal aggregates with 0% fines) after 7, 14 and 28 days of curing were 13.58 MPa, 20.12 MPa and 23.2 MPa respectively. For batch B₂ (having normal aggregates with 8% fines) the average compressive strength values of samples after 7, 14 and 28 days of curing were 14.98 MPa, 23.02 MPa and 27.5 MPa respectively as seen in **Fig. 12** graph of average compressive strength results of batch B₂ pervious concrete cubes (8%fines) after 7, 14 ad 28 days of curing and for batch B₃ (having normal aggregates with 15% fines) the average compressive strength values of samples after 7, 14 and 28 days of curing were 17 MPa, 25.78 MPa and 31.34 MPa respectively as seen in **Fig. 13** graph of average compressive strength results of batch B₃ pervious concrete cubes (15%fines) after 7, 14 ad 28 days of curing. The above results confirm a clear trend where the compressive strength of pervious concrete improves with increase in fine aggregate content which leads to better particle packing, reducing void ratio and contributing to a denser, more robust structure.

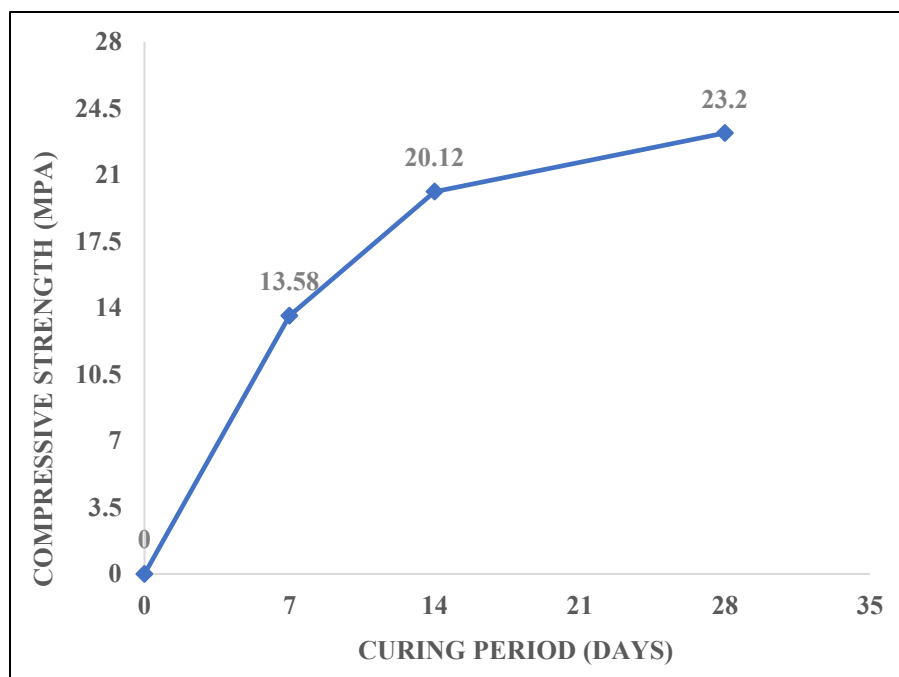


Fig. 11 Graph showing average compressive strength results of batch B₁ Pervious concrete cubes (0% fines) after 7, 14 ad 28 days of curing

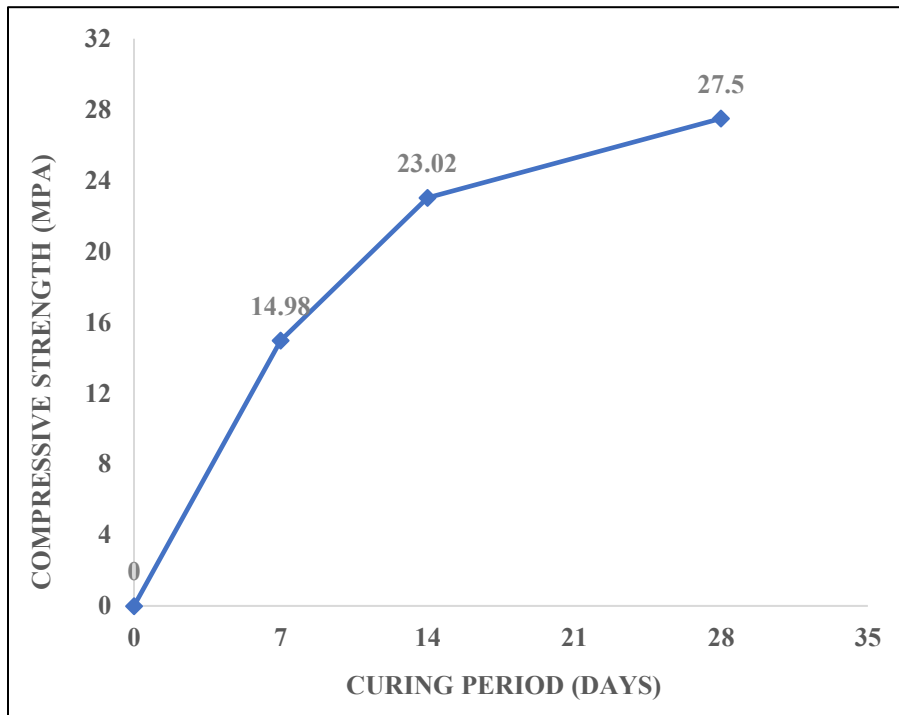


Fig. 12 Graph showing average compressive strength results of batch B₂ Pervious concrete cubes (8% fines) after 7, 14 ad 28 days of curing

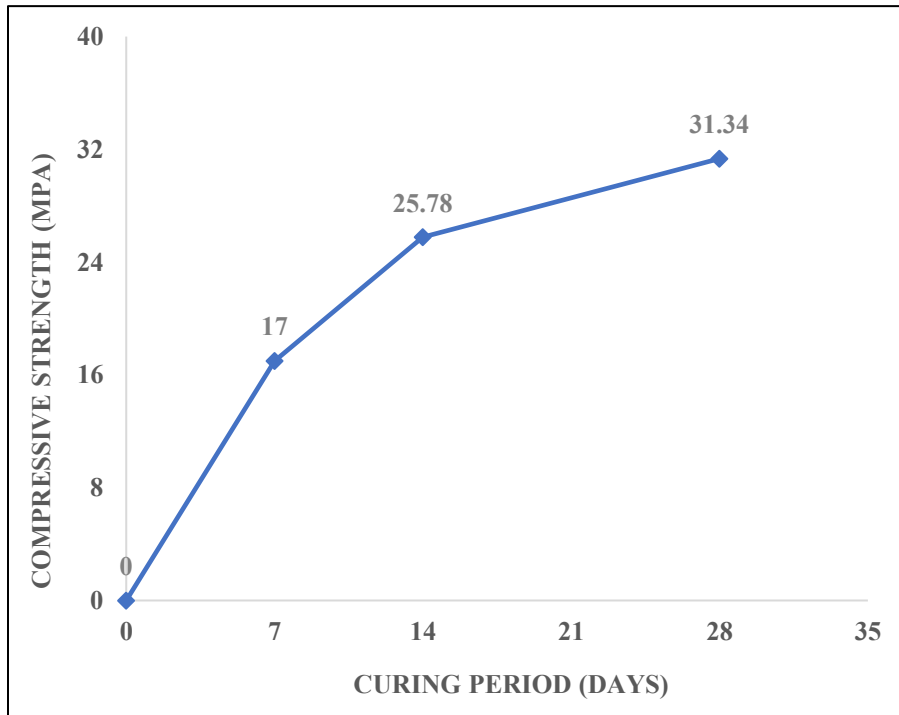


Fig. 13 Graph showing average compressive strength results of batch B₃ Pervious concrete cubes (15% fines) after 7, 14 ad 28 days of curing

3.2.2 Compressive strength test results of pervious concrete cubes with coarse aggregates of angularity number 9.9

Figures 14 to 16 have shown the average compressive strength values for batches B₄, B₅ and B₆ having different percentages of fine aggregate (0% fines for B₄, 8% fines for B₅ and 15% fines for B₆) after 7, 14 and 28 days of curing. It can be seen from **Fig. 14** graph of average compressive strength results of batch B₄ pervious concrete cubes (0%fines) after 7, 14 ad 28 days of curing that the average compressive strength values of batch B₄ samples (high angularity with 0% fines) after 7, 14 and 28 days of curing were 15.74 MPa, 23.62 MPa and 27.76 MPa respectively. For batch B₅ (high angularity with 8% fines) the average compressive strength values of samples after 7, 14 and 28 days of curing were 17.35 MPa, 27.16 MPa and 31.95 MPa respectively as seen in **Fig. 15** graph of average compressive strength results of batch B₅ pervious concrete cubes (8%fines) after 7, 14 ad 28 days of curing and for batch B₆ (high angularity with 15% fines) the average compressive strength values of samples after 7, 14 and 28 days of curing were 20.94 MPa, 29.98 MPa and 36.64 MPa respectively as seen in **Fig. 16** graph of average compressive strength results of batch B₆ pervious concrete cubes (15%fines) after 7, 14 ad 28 days of curing. It can be clearly seen from the above results that high angularity of aggregates resulted in improved compressive strength for various percentages of fine aggregate due to better bonding of particles and reduced void ratio as compared to normal aggregates of angularity number 6.9.

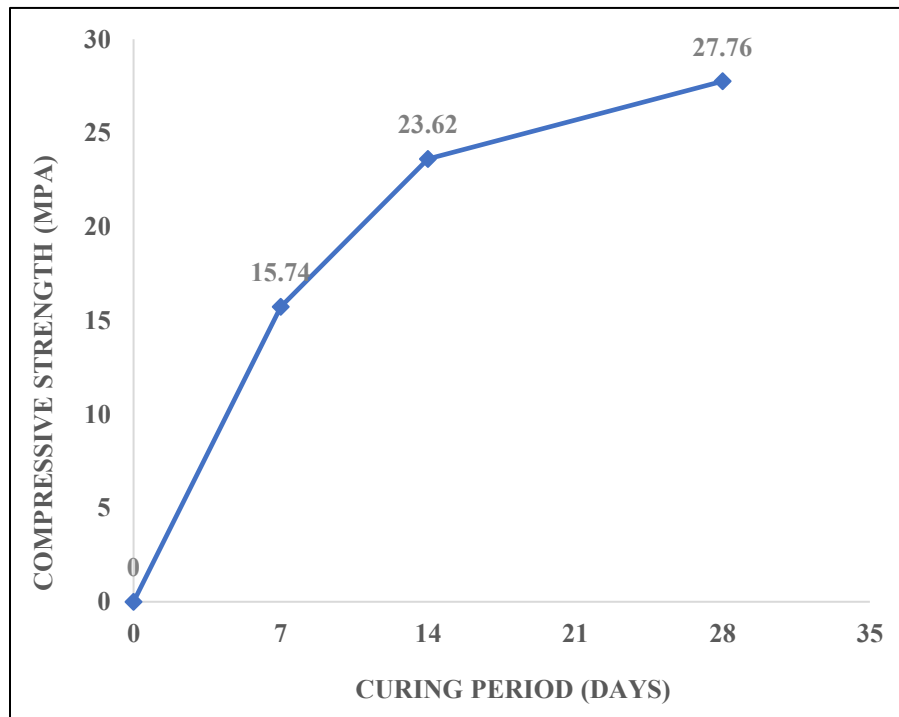


Fig. 14 Graph showing average compressive strength results of batch B₄ Pervious concrete cubes (0% fines) after 7, 14 ad 28 days of curing

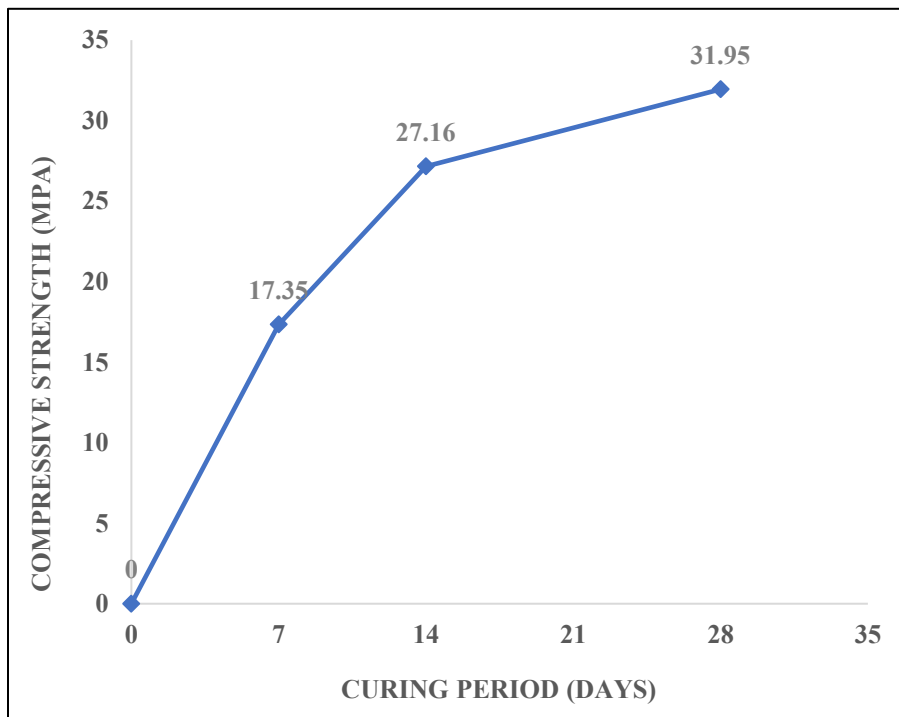


Fig. 15 Graph showing average compressive strength results of batch B₅ Pervious concrete cubes (8% fines) after 7, 14 ad 28 days of curing

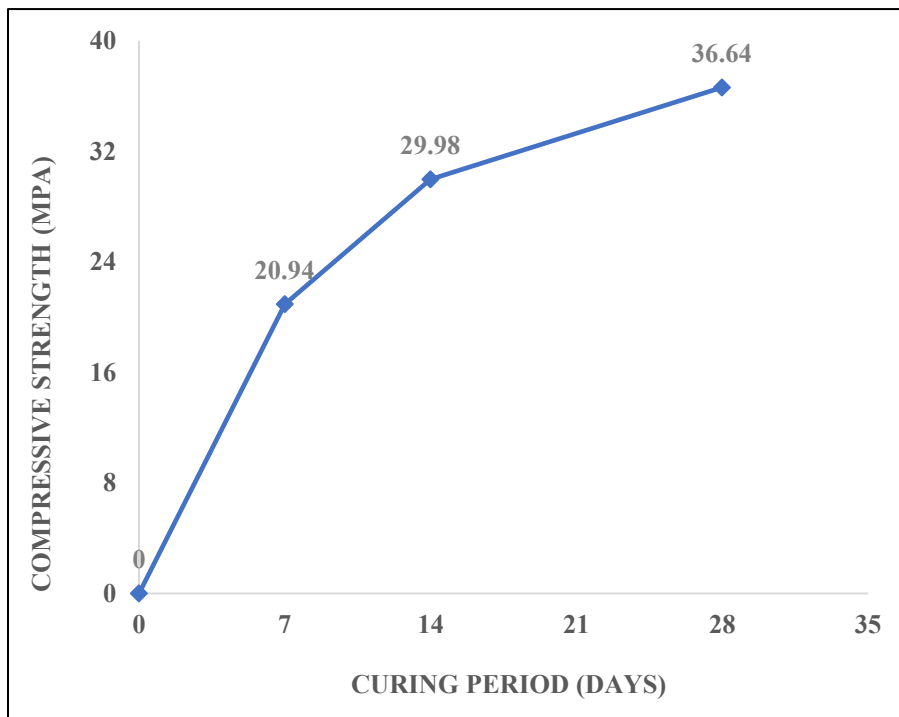


Fig. 16 Graph showing average compressive strength results of batch B₆ Pervious concrete cubes (15% fines) after 7, 14 ad 28 days of curing

3.2.3 Compressive strength test results of pervious concrete cubes with coarse aggregates of angularity number 2.3

Figures 17 to 19 have shown the average compressive strength values for batches B₇, B₈ and B₉ having different percentages of fine aggregate (0% fines for B₇, 8% fines for B₈ and 15% fines for B₉) after 7, 14 and 28 days of curing. It can be seen from **Fig. 17** graph of average compressive strength results of batch B₇ pervious concrete cubes (0%fines) after 7, 14 ad 28 days of curing that the average compressive strength values of batch B₇ samples (rounded aggregates with 0% fines) after 7, 14 and 28 days of curing were 10.86 MPa, 16.10 MPa and 18.56 MPa respectively. For batch B₈ (rounded aggregates with 8% fines) the average compressive strength values of samples after 7, 14 and 28 days of curing were 11.98 MPa, 18.40 MPa and 19.57 MPa respectively as seen in **Fig. 18** graph of average compressive strength results of batch B₈ pervious concrete cubes (8%fines) after 7, 14 ad 28 days of curing and for batch B₉ (rounded aggregates with 15% fines) the average compressive strength values of samples after 7, 14 and 28 days of curing were 13.60 MPa, 20.60 MPa and 24.27 MPa respectively as seen in **Fig. 19** graph of average compressive strength results of batch B₉ pervious concrete cubes (15%fines) after 7, 14 ad 28 days of curing. The above findings show that the percentage of fine aggregate and the pervious concrete's compressive strength are positively correlated. The above data suggests that the inclusion of fine aggregate up to 15% contributes positively to the compressive strength of pervious concrete likely due to enhanced bonding between the cement paste and aggregate particles improving the material's structural integrity.

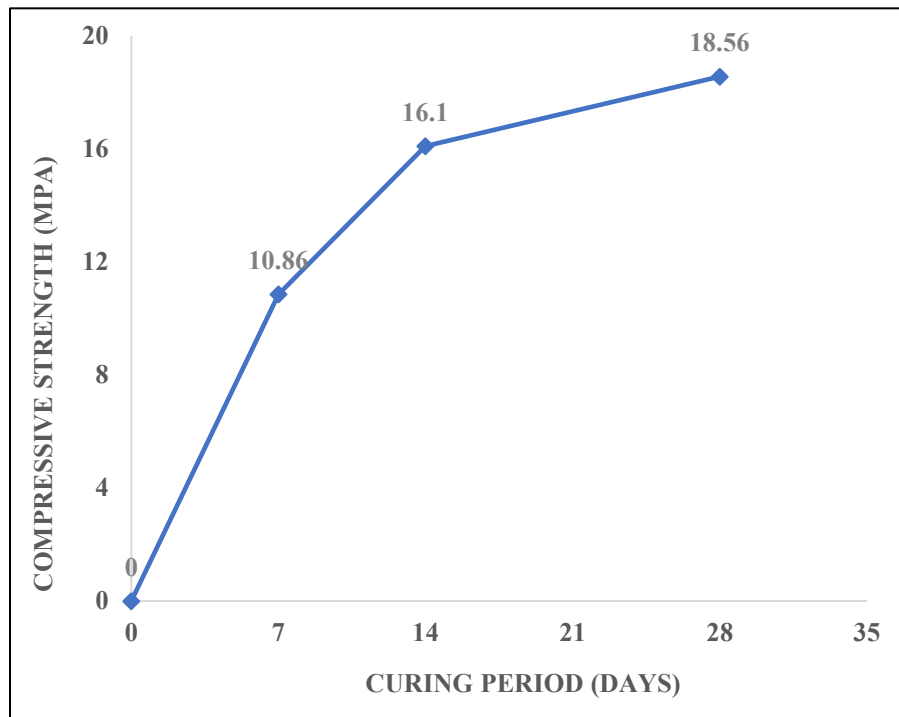


Fig. 17 Graph showing average compressive strength results of batch B₇ Pervious concrete cubes (0% fines) after 7, 14 ad 28 days of curing

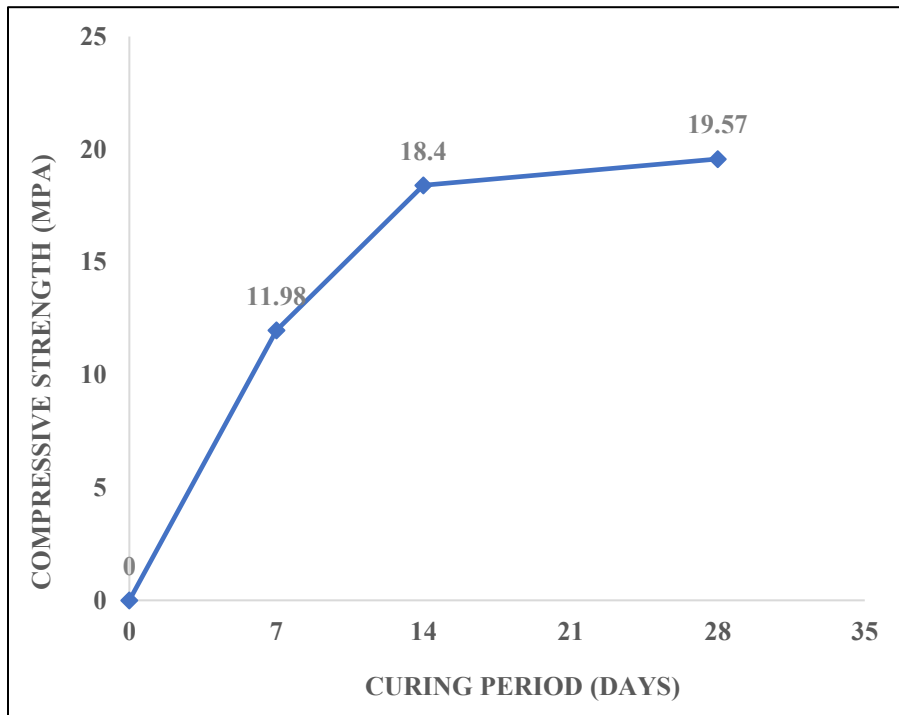


Fig. 18 Graph showing average compressive strength results of batch B₈ Pervious concrete cubes (8% fines) after 7, 14 ad 28 days of curing

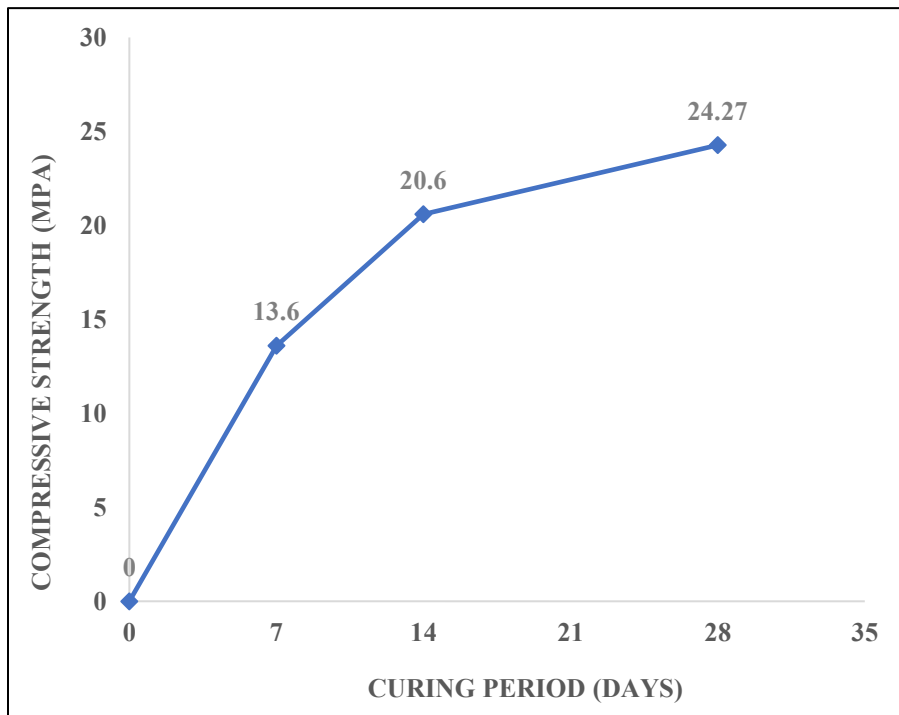


Fig. 19 Graph showing average compressive strength results of batch B₉ Pervious concrete cubes (15% fines) after 7, 14 ad 28 days of curing

In summary, the above test results performed on angular and rounded pervious concrete cubes show that less rounded aggregates increased the strength of pervious concrete by approximately 15-17% due to better bonding. The rougher surfaces and larger surface area of the angular aggregates also prevent the paste from flowing to the bottom of the concrete sample, contributing to a stronger bond. In addition, the considerable friction between the angular aggregates resists compression along the paste joint resulting in higher compressive strength. However this also leads to lower throughput. Conversely more rounded aggregates increase permeability but decrease strength. Therefore, optimizing aggregate shape is essential to balance strength and drainage in pervious concrete applications.

3.3 Permeability test results of pervious concrete cubes

3.3.1 Permeability test results of pervious concrete cubes with normal and high angularity coarse aggregates

After performing the permeability test on pervious concrete samples with normal coarse aggregates (angularity number 6.9) after 28 days of curing, the results revealed that as the fine aggregate content increased from 0% to 15%, the permeability of the pervious concrete decreased significantly (2.56 mm/s for pervious concrete samples with 0% fines, 1.11 mm/s for pervious concrete samples with 8% fines and 0.50 mm/s for pervious concrete samples with 15% fines) as shown in **Fig. 20** bar chart comparing permeability test results of pervious concrete cubes with normal, angular and rounded coarse aggregates for 0%, 8% and 15% of fine aggregate content. Similarly, for pervious concrete samples with high angularity coarse aggregates (angularity number 9.9), the results showed that with increase in fine aggregate percentage from 0 % to 15 %, the permeability of pervious concrete decreased (1.92 mm/s with 0% fines, 0.78 mm/s with 8 % fines and 0.32 mm/s with 15 % fines) as shown in **Fig. 20**. This was mainly due to the increased filling of voids with fine aggregates which reduced the interconnected pore structure within the concrete. The finer particles filled the larger voids thereby leading to a denser and less permeable matrix. Consequently, water had a slower passage through the samples with high angularity aggregates when compared to the samples with normal angularity aggregates as the interconnected pore spaces became smaller and more compact. This reduction in permeability is a direct result of the finer particles and angularity of coarse aggregates reducing the overall void ratio (Kwan et al. 2014).

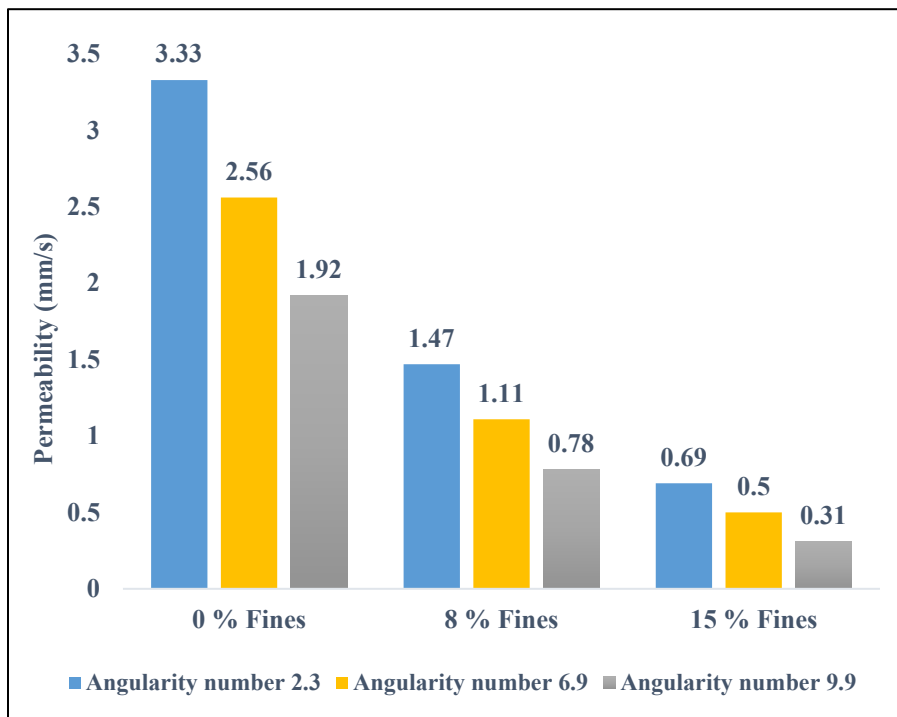


Fig. 20 Bar chart comparing permeability test results of pervious concrete cubes with normal, angular and rounded coarse aggregates for 0%, 8% and 15% of fine aggregate content

3.3.2 Permeability test results of pervious concrete cubes with rounded coarse aggregates

When the permeability test was performed on the pervious concrete samples having rounded aggregates (angularity number 2.3) after 28 days of curing, it was observed that the permeability of the pervious concrete was significantly higher even with the inclusion of fine aggregates (3.33 mm/s for pervious concrete samples with 0% fines, 1.47 mm/s for pervious concrete samples with 8% fines and 0.69 mm/s for pervious concrete samples with 15% fines) as shown in **Fig. 20**. The smooth and curved shape of the aggregates allow them to pack less efficiently creating larger voids between particles (MD. Tasnimul Arshad 2023). The rounded aggregates due to their lack of angularity do not fit as snugly together thus maintaining larger aggregate voids that promote better flow of water. These larger voids enhance the overall porosity of concrete which is critical in pervious concrete applications where drainage is the primary function (MD. Tasnimul Arshad 2023). As a consequence, even with increasing fine aggregate content which would typically reduce permeability by filling void spaces, the permeability of the concrete remains higher in mixtures with rounded aggregates. The reason for this is that the overall structure of the concrete with its larger interconnected voids still facilitates faster water passage through the material. Therefore, rounded aggregates contribute to a more permeable pervious concrete (MD. Tasnimul Arshad 2023). The overall porosity of pervious concrete is another important factor influencing permeability. Pervious concrete typically requires a porosity range of 15-25% to allow adequate water drainage (Chen et al. 2013; Moretti et al. 2019). While rounded aggregates contribute to larger voids

between particles, the overall void ratio must be carefully managed to maintain the desired porosity. Binder content plays a critical role in the balance between permeability and strength in pervious concrete (Charu L Durge 2024). A higher cement content improves the strength of the concrete but can reduce permeability by filling voids within the aggregate matrix. Conversely, reducing the binder content can enhance permeability but may compromise the concrete's structural integrity (Charu L Durge 2024). The water-cement ratio (w/c ratio) further affects both strength and permeability (Yang et al. 2018).

4. Conclusion

This project has comprehensively evaluated the strength and permeability characteristics of pervious concrete with varying fine aggregate contents (specifically focusing on 0%, 8%, and 15% fine aggregates) and shape of aggregates (normal, highly angular and rounded).

4.1 Following are the main conclusions that can be drawn from the findings of the present study:

1. With increase in the fine aggregate content (from 0% to 15%) the permeability of the pervious concrete decreased but the compressive strength significantly increased. Conversely, with decrease in the percentage of fine aggregate content (from 15% to 0%) the permeability of pervious concrete increased significantly but at the cost of reduced compressive strength.
2. The shape of coarse aggregates also played a critical role in deciding the performance of pervious concrete.
3. High angularity coarse aggregates (having angularity number 9.9) ensured better bonding between aggregates resulting in higher compressive strength but less permeability as compared to rounded coarse aggregates (having angularity number 2.3) while as rounded aggregates showed better permeability results but reduced compressive strength results when compared to angular aggregates. Normal coarse aggregates (with angularity number 6.9) maintained a favourable balance between compressive strength and permeability when incorporated with 8 % fine aggregate content.
4. The use of smaller aggregates contributes positively to the performance of pervious concrete. Smaller aggregates help create a well-distributed matrix enhancing the interlocking of particles which further supports the structural integrity of the concrete while maintaining necessary void spaces for water infiltration.
5. Incorporating chemical admixtures (polycarboxylate ether-based superplasticizer) significantly improved workability allowing for a lower w/c ratio which boosted strength and durability of pervious concrete.
6. Flaky aggregates negatively affected both strength and porosity due to weaker particle bonding and poor mutual bonding.

7. It was concluded that among the tested concrete mixes, the pervious concrete cubes having 8% fine aggregate content with normal coarse aggregates (angularity number 6.9) provided the best and optimal balance between compressive strength and permeability with compressive strength of 14.98 MPa after 7 days of curing, 23.02 MPa after 14 days of curing and 27.5 MPa after 28 days of curing and permeability of 1.11 mm/s after 28 days of curing.
8. Further explorations regarding the long-term performance of the materials under prolonged exposure to environmental factors like freezing, thawing and clogging is necessary and solutions for maintaining permeability such as cleaning techniques incase of clogging require further validation in real world conditions.

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