Journal of Engineering Issues and Solutions

Compressive Strength of Porous Concrete Using Course Aggregate as a Partial Replacement for Fine Aggregate

Aashish Bhandari[1], Aayush Ranabhat[2], Bibek Koirala[3], Bipin Poudel[4], Saurav Bhandari[5], Saugat Tiwari[6]*, Sanjay Baral[7], Badri Adhikari[8], Rishav Khanal[9]

[1,2,3,4,5,6,7,8,9]*School of Engineering, Faculty of Science and Technology, Pokhara University*

**Corresponding mail: Saugat.tiwari@pu.edu.np*

Received: May 12, 2026; Revised: 13 June, 2026; Accepted: July 11, 2026

Abstract

Pervious concrete is a special type of lightweight concrete that is mainly made of cement, coarse aggregates, and water. This study looks at how the strength and porosity of concrete change when fine aggregate is partly replaced by coarse aggregate. Concrete of M15 grade was prepared using different levels of fine aggregate replacement with coarse aggregate. Cube specimens of 150mm x 150mm x 150mm were cast and kept under normal water curing conditions. The study tested porous concrete with 60%, 70%, 80%, and 90% sand replacement and checked the compressive strength at 3,7,14, and 28 days. The compressive strength increased from 10.2 MPa at 60% replacement to a peak of 12.42 MPa at 80%, then dropped to 9.99 MPa at 90%. This shows that 80% sand replacement gives the best performance among all the mixes tested. The results show a clear link between aggregate type and concrete strength. As the replacement level increased, porosity also increased, which affected the strength. Overall, porous concrete shows good potential as a sustainable pavement material, particularly in urban areas where drainage matters. The study concludes that by controlling how much fine aggregate is replaced, a good balance between strength and porosity can be achieved. This makes porous concrete a suitable choice for low load areas such as pedestrian pathways and parking areas.

Keyword: *Compressive Strength, Fine Aggregate Replacement, Pervious Concrete, Sustainable Pavement*

Introduction

Several researchers have studied the behavior of pervious concrete in terms of compressive strength, porosity, aggregate size, and mix design. Their findings provide a strong base for understanding how porous concrete works and what factors affect its performance. One of the key studies investigated the 7 and 28 day compressive strength of pervious concrete by reducing fine aggregate from zero to 100% in the mix design. It was found that as fine aggregate was reduced, the compressive strength of pervious concrete also decreased (Zhu et al., 2025). The maximum reduction in compressive strength was 49.82% at 7 days and 46.25% at 28 days when sand was fully removed from the mix. The study also found that reducing fine aggregate from 0 to 40% did not allow any water infiltration at all. However, the highest infiltration rate increased by 273.11% when 100% of the fine aggregate was removed. A 90% reduction of sand gave a compressive strength of 2150 psi and an infiltration rate of 165.79 inch per hour, which was considered suitable for parking and walking area pavements (Aneel Manan, 2018).

Building on this, another study looked at how the physical properties of aggregates affect the strength of pervious concrete. It concluded that the size of coarse aggregate, water to cement ratio, and aggregate to cement ratio play a very important role in determining strength (Ahmad et al., 2024). Using smaller sized aggregate of 10mm was found to give better compressive strength compared to larger sized aggregate of 20mm. As aggregate size increases, the void ratio also increases, which causes a reduction in compressive strength (Ukpata et al., 2024). This finding was further supported by another researcher who stated that smaller coarse aggregate sizes tend to produce both higher compressive strength and better permeability (Hui et al., 2025), and that mixes with a higher aggregate to cement ratio are more suitable for pavements that need low compressive strength and high permeability (Nataraja et al., 2023).

In relation to mix design parameters, aggregate size and water to cement ratio were identified as the most important factors influencing the compressive strength of porous concrete. While adding fine aggregate or replacing cementations materials can improve strength, increasing the fines content may reduce the drainage capacity of the concrete (Tiwari, 2022). This shows that there is a direct tradeoff between strength and permeability, and finding the right balance in the mix design is very important (Ekolu et al., 2025). On a broader level, porous concrete generally shows much lower compressive strength compared to conventional concrete with a similar water to cement ratio. As the void content increases, the compressive strength decreases. The average compressive strength of porous concrete is around 20 MPa, with recorded values ranging from as low as 2.0 MPa to as high as 34.5 MPa (Rajab Abousnina, 2025). These values confirm that porous concrete can still provide usable strength depending on how the mix is designed and proportioned.

Regarding mix design guidelines, pervious concrete is known as gap graded concrete and requires a minimum porosity of 15%. It is usually made using coarse aggregates of size 19.00 to 19.50 mm to maintain the void structure, though many researchers have also used aggregate sizes in the range of 2.36 to 9.50 mm to improve its properties. The main goal in pervious concrete mix design is to achieve a good balance between voids, cement paste, workability, and strength. ACI 2010 recommends a trial and error method along with field testing to achieve the desired mix properties (Mudasir Nazeer, 2020). The studies reviewed above clearly show that controlling aggregate size, fine aggregate content, and mix proportions is very important in producing porous concrete that has both good strength and adequate permeability. These findings directly support the experimental approach taken in this study, where fine aggregate is partially replaced by coarse aggregate to find the most suitable mix for practical and sustainable construction use.

Methodology

Research methodology describes the overall plan and process followed in a study to collect, analyze, and interpret data in a reliable and valid way as shown in figure 1. It explains the steps taken to answer the research questions and directly affects the credibility and accuracy of the study findings. In simple terms, methodology refers to the complete set of techniques and steps used to identify, select, process, and analyze information about a given topic.

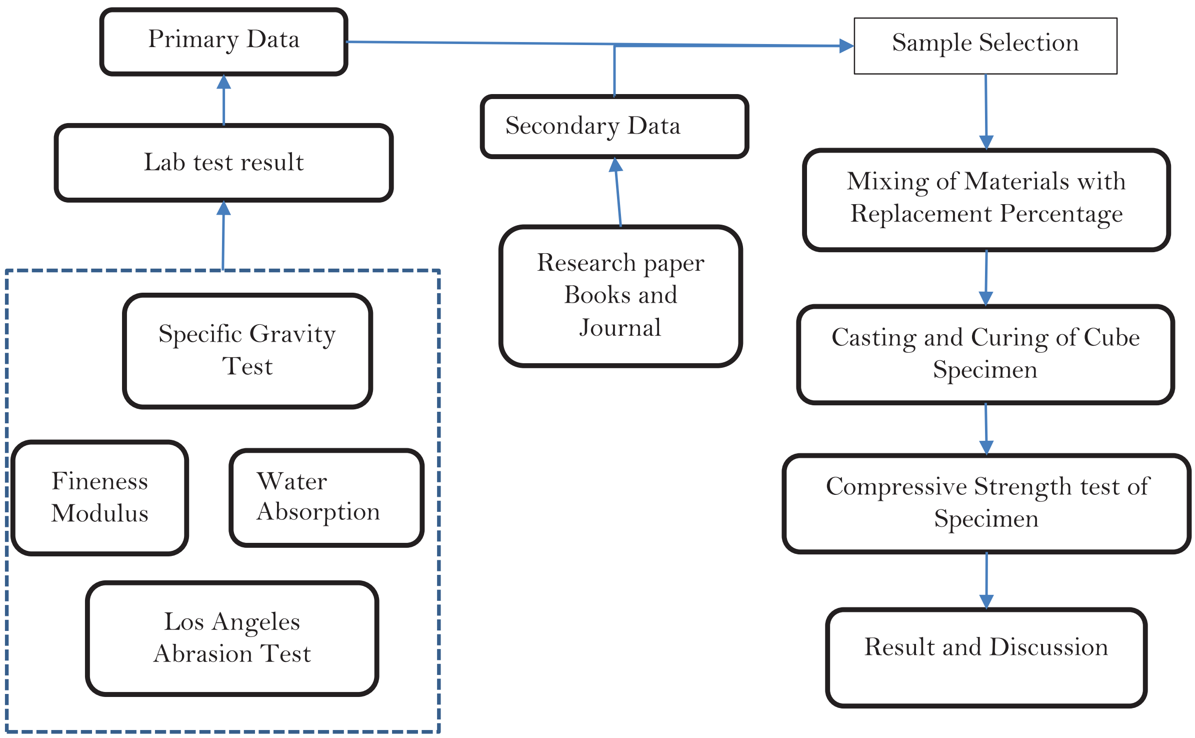


Figure 1: Research Framework

In this study, a quantitative and experimental research approach is used to evaluate the compressive strength, porosity, and workability of porous concrete. The research involves partial replacement of fine aggregate with coarse aggregate at different percentage levels, preparation of M15 grade porous concrete mixes, casting of cube specimens, and curing for specified durations. Compressive strength tests are carried out at 3, 7, 14, and 28 days to observe how strength develops over time under different mix conditions. The test results are measured and analyzed to understand the effect of aggregate replacement on the performance of porous concrete and to verify the relationship between porosity and strength. The overall methodology is designed to systematically determine the most suitable mix proportion that offers the best balance between strength and permeability (Sánchez-Mendieta et al., 2024).

All materials including cement, fine aggregate, coarse aggregate, and water were collected from the SOE Civil Engineering Lab. Aggregates were properly washed and air dried before use to remove dust and impurities. Ordinary Portland cement of 43 grade was used as the binding material due to its good early strength development and wide availability. Natural River sand with a specific gravity of 2.62 was used as fine aggregate, which was clean, well graded, and free from organic impurities. Crushed angular coarse aggregate with a size ranging between 4.75 mm and 12.5 mm and a specific gravity of 2.72 was used as the primary constituent of the mix. Angular aggregates were selected because of their better interlocking properties, which improve strength compared to rounded aggregates (Ali et al., 2023). Clean potable water free from harmful impurities was used for both mixing and curing to ensure proper hydration of cement. The mixing of porous concrete was done by hand mixing as shown in figure 2 (A), starting with dry mixing of cement and coarse aggregates until a uniform color was obtained, followed by gradual addition of water to ensure proper coating of aggregates with cement paste. The moulds were cleaned, oiled, and filled with concrete in three equal layers, each compacted with not less than 15 strokes using a tamping rod, and the top surface was finished smoothly with a trowel. After removing the moulds, the specimens were cured with wet jute bags for 28 days to maintain moisture and improve strength as shown in figure 2.

(A) (B) (C) (D)

Figure 2: A) Hand Mixing B) Casting of cube in mould C) Curing with jute bag, D) Porous Concrete

Compressive strength tests were carried out on 150 mm x 150 mm x 150 mm cube specimens at 3,7,14 and 28 days using a compression testing machine, where the maximum load at failure was recorded and compressive strength was calculated by dividing the load by the cross sectional area.

Result and Discussion

Several material tests were conducted to determine the physical properties of the aggregates used in this study. The specific gravity of fine aggregate was found to be 2.62 and that of coarse aggregate was 2.72, both determined using the pycnometer method. Water absorption tests showed that fine aggregate absorbed 2.71% of water and coarse aggregate absorbed 2.04%, both of which are within acceptable limits for use in concrete. The fineness modulus test for fine aggregate confirmed that the sand used falls under Zone I as per IS 383-1970, which refers to coarse sand that is suitable for concrete work requiring high strength. The Los Angeles Abrasion test was also carried out to check the hardness and durability of the coarse aggregate. The original sample weight was 5000 g and the weight retained on the 1.7 mm sieve after the test was 3860 g, giving an abrasion value of 24.8%. This value is within the acceptable range for concrete work, confirming that the coarse aggregate used in this study is hard, durable, and less affected by abrasion, making it suitable as a standard aggregate for the preparation of porous concrete.

The compressive strength of porous concrete increased with curing age for all fine aggregate replacement levels, indicating continuous hydration and strength development over time (Shanthi Vengadeshwari et al., 2025). Among the mixes, the 80% fine aggregate replacement showed the highest compressive strength, attaining approximately 12.4 MPa at 28 days, which suggests optimum performance at this replacement level as shown in figure 3. In contrast, the 90% replacement mix exhibited comparatively lower strength due to increased void content and weaker aggregate bonding. The small error bars indicate good consistency and reliability of the experimental results. Overall, the study demonstrates that curing age and fine aggregate replacement percentage significantly influence the compressive strength behavior of porous concrete.

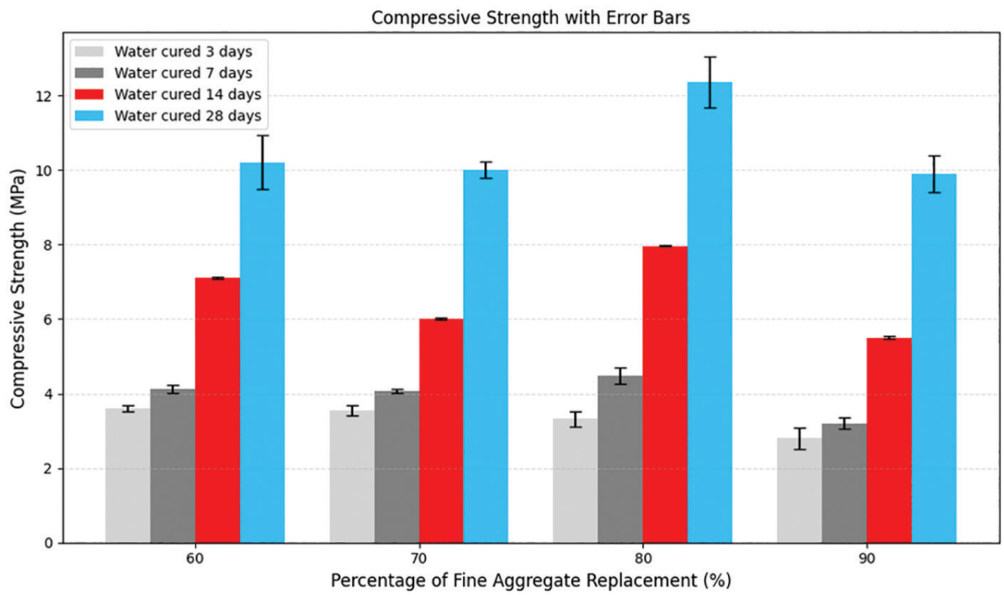
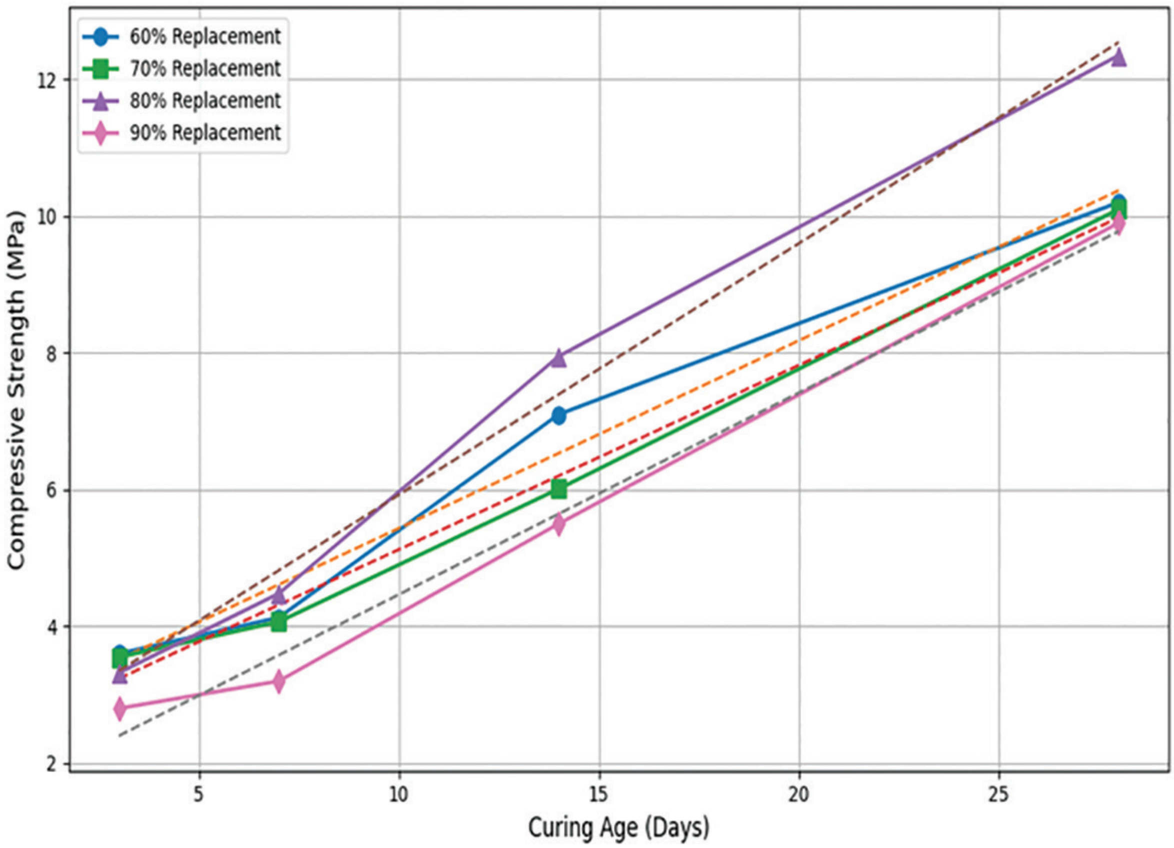


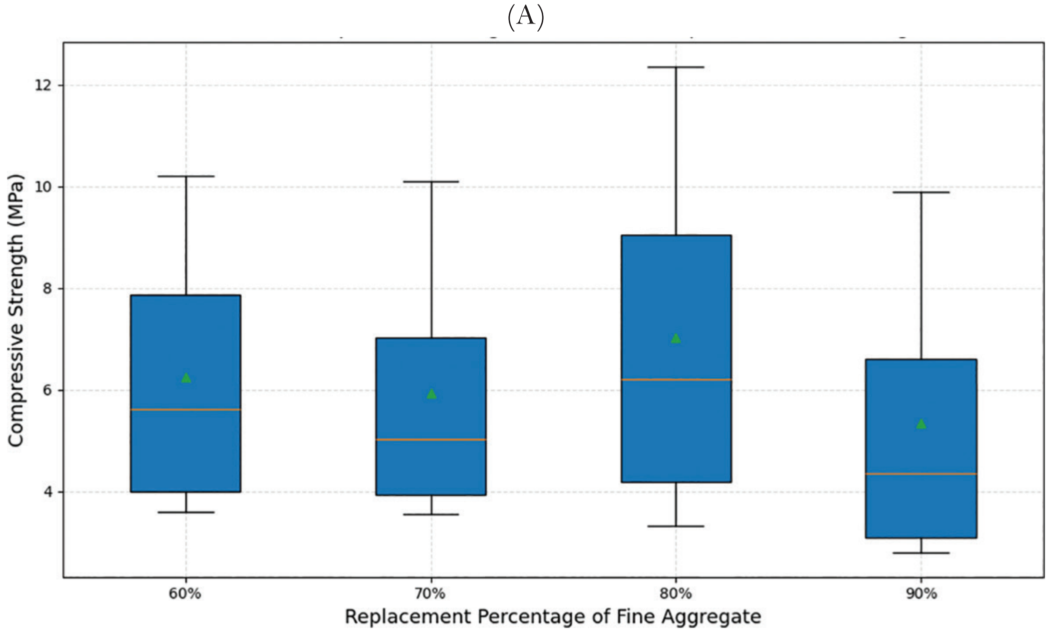
Figure 3: Compressive Strength Development of Porous Concrete with Different RCA Replacement Percentages under Water Curing Conditions.

The figure 4(A) shows compressive strength development of concrete mixes with 60%, 70%, 80%, and 90% cement replacement levels, tested at 3, 7, 14, and 28 days of curing. At 3 days, all mixes performed similarly, with strengths ranging from 2.8 to 3.7 MPa. The 60% replacement mix had the highest early strength while the 90% mix started lowest. This indicates that early hydration was not significantly affected by the replacement level.

Between 7 and 14 days, the 80% replacement mix gained strength faster than the others, reaching nearly 7.9 MPa at 14 days. The remaining mixes showed slower and more comparable growth during this period. At 28 days, the 80% replacement mix reached the highest strength at about 12.3 MPa, which was higher than all other mixes. The 60% and 70% mixes both reached around 10.1 MPa, and the 90% mix reached 9.9 MPa. This shows that a higher replacement level does not always reduce final strength. The 80% mix performed best overall, likely due to a more active pozzolanic reaction at that proportion. Beyond 80% replacement, strength slightly dropped, suggesting that too little cement content begins to limit proper hydration. The trend lines as shown if figure 4 (A) support a continued upward strength gain for all mixes, with the 80% mix showing the steepest projected growth.



(A)



(B)

Figure 4: A) Compressive Strength Vs Curing age and Trend Analysis, B) Box Plot of Compressive Strength for Different Replacement Percentage

The box plot shown if figure 4(B), analysis of compressive strength for different replacement percentages of fine aggregate indicates that strength characteristics improved progressively up to 80% replacement and decreased thereafter at 90% replacement. Among all mixtures, the 80% replacement level exhibited the highest mean and median compressive strength values, demonstrating superior mechanical performance and improved aggregate interlocking characteristics. Although the 80% mix showed relatively higher variability, it achieved the greatest overall strength development compared to other replacement levels. In contrast, the 90% replacement mix showed lower strength values, suggesting that excessive replacement adversely affects the bonding and matrix densification of the concrete. Therefore, based on the statistical distribution and strength performance, 80% replacement of fine aggregate can be considered the optimum proportion for enhancing compressive strength characteristics.

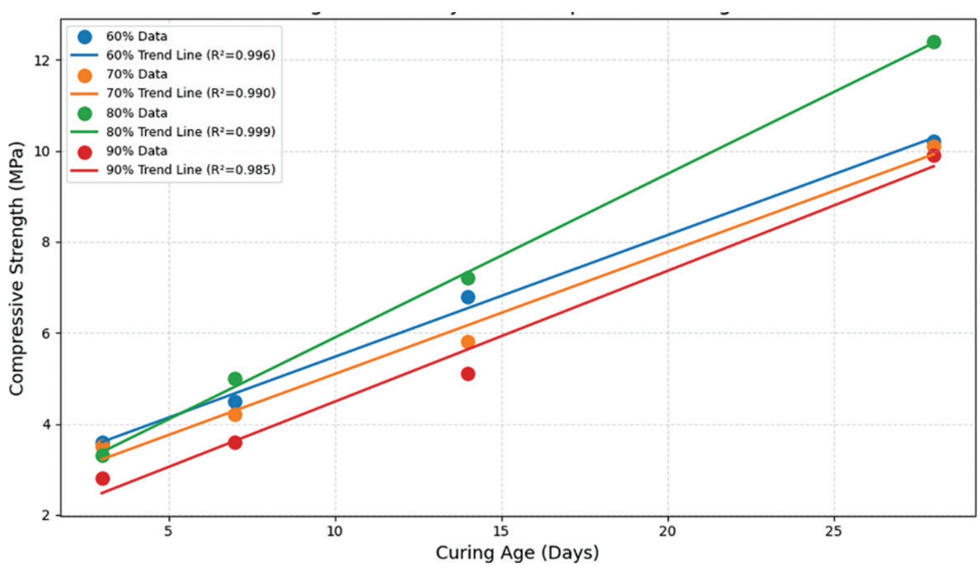


Figure 5: Regression Analysis of Compressive Strength

The figure 5 presents a regression analysis of compressive strength development for four cement replacement levels, 60%, 70%, 80%, and 90%, over a curing period of 3 to 28 days. All four mixes show a strong linear relationship between curing age and compressive strength. The R^2 values for all mixes are very close to 1, specifically 0.996 for 60%, 0.990 for 70%, 0.999 for 80%, and 0.985 for 90%. These high values confirm that curing age is a very reliable predictor of strength gain in all mixes, and the linear model fits the data well.

The 80% replacement mix has the highest R^2 value of 0.999 and the steepest trend line slope, meaning its strength grew most consistently and rapidly with curing time. It reached approximately 12.4 MPa at 28 days, which was the highest among all mixes. The 60% and 70% replacement mixes show nearly identical trend line slopes and converge at around 10 MPa by 28 days. Their data points follow the trend lines closely throughout the curing period. The 90% replacement mix has the lowest R^2 value of 0.985 and the flattest slope, indicating slightly more variability and a slower rate of strength gain. It reached close to 9.9 MPa at 28 days, which was the lowest final value. The regression analysis confirms that strength gain follows a consistent and predictable linear trend across all replacement levels. The 80% mix shows the best fit and the highest strength development rate, making it the most efficient mix in terms of long term strength performance. During the compressive strength test of PCC, vertical cracks were observed parallel to the direction of loading, indicating axial splitting failure as shown in figure 6. As per IS 516, plain concrete specimens under compression commonly fail due to the development of lateral tensile stresses. When these tensile stresses exceed the low tensile strength of PCC, vertical cracks form and propagate rapidly. Since PCC contains no reinforcement, the failure was sudden and brittle (Katakam et al., 2025). The maximum compressive strength obtained was 12.42 MPa.

(A) (B)

Figure 6: A & B development of cracks

The comparative study on compressive strength development revealed that conventional M15 concrete exhibited higher strength than porous concrete at both 7 and 28 days of curing. Conventional concrete achieved strengths of 11.02 MPa and 16.32 MPa at 7 and 28 days respectively (Sai Sindhu K, 2015), with an overall strength gain of 48.09%. In comparison, porous concrete (80% replacement) attained 4.5 MPa at 7 days and 12.42 MPa at 28 days, showing a significantly higher strength increment of 176% during the curing period. Although porous concrete demonstrated lower early-age strength due to its higher void content and reduced bonding, it exhibited substantial later-age strength development, thereby reducing the strength difference between the two concretes at 28 days (Nataraja et al., 2023).

Conclusion

The study evaluated the compressive strength development of porous concrete with fine aggregate replacement levels of 60%, 70%, 80%, and 90% over curing periods of 3, 7, 14, and 28 days. The results clearly demonstrate a continuous increase in compressive strength with curing age for all mix proportions, confirming effective cement hydration and progressive bonding within the porous concrete matrix. Among all the mixes, the 80% fine aggregate replacement consistently exhibited superior performance, achieving the highest compressive strength of 12.42 MPa at 28 days. The comparative analysis indicates that although all mixes followed a similar strength development trend, the 80% replacement mix showed the most efficient strength gain, particularly after 7 days of curing, suggesting enhanced internal matrix formation and improved inter-particle bonding. In contrast, the 90% replacement mix recorded the lowest strength at all curing ages, indicating that excessive replacement adversely affects cementations bonding due to reduced cement content. Statistical and regression analyses further confirmed a strong linear relationship between curing age and compressive strength for all mixes, with R^2 values close to unity, validating the reliability of the observed strength trends. The box plot analysis also supported that the 80% replacement level achieved the highest mean and median strength values, although with slightly higher variability. In comparison with conventional M15 concrete, porous concrete showed lower absolute strength values; however, it exhibited a significantly higher percentage strength gain during curing, indicating strong later-age development. Despite this improvement, porous concrete remained suitable primarily for light-load applications such as pedestrian pathways, garden walkways, and low-traffic surfaces. Overall, 80% fine aggregate replacement is identified as the optimum level for balancing strength performance and porosity characteristics in porous concrete.

References

Agar-Ozbek, A. S., Weerheijm, J., Schlangen, E., & Van Breugel, K. (2013). Investigating porous concrete with improved strength: Testing at different scales. Construction and Building Materials, 41, 480-490.

Ahmad, S. A., Ahmed, H. U., Rafiq, S. K., Jafer, F. S., & Fqi, K. O. (2024). A comparative analysis of simulation approaches for predicting permeability and compressive strength in pervious concrete. Low-carbon Materials and Green Construction, 2(1), 10. https://doi.org/10.1007/s44242-024-00041-x

Aneel Manan a, M. A. (2018). Experimental Investigation of Compressive Strength and Infiltration Rate of Pervious Concrete by Fully Reduction of Sand .

Ali, U., Kikumoto, M., Ciantia, M., Cui, Y., & Previtali, M. (2023). Systematic effect of particle roundness/angularity on macro- and microscopic behavior of granular materials. Granular Matter, 25(51). https://doi.org/10.1007/s10035-023-01341-y

Bhutta, M. A. R., Hasanah, N., Farhayu, N., Hussin, M. W., bin Md Tahir, M., & Mirza, J. (2013). Properties of porous concrete from waste crushed concrete (recycled aggregate). Construction and building materials, 47, 1243-1248.

Carlos Sánchez-Mendieta, C., Galán-Díaz, J. J., & Martinez-Lage, I. (2024). Relationships between density, porosity, compressive strength and permeability in porous concretes: Optimization of properties through control of the water-cement ratio and aggregate type. Journal of Building Engineering, 97, 110858. https://doi.org/10.1016/j.jobe.2024.110858

Chen, S., Wang, Y., Dai, W., Yang, H., Wang, D., & Lv, Y. (2024). Recycled aggregate porous concrete: Pore structure, clogging properties and models. Construction and Building Materials, 417, 135344.

Chindaprasirt, P., Hatanaka, S., Chareerat, T., Mishima, N., & Yuasa, Y. (2008). Cement paste characteristics and porous concrete properties. Construction and Building materials, 22(5), 894-901.

Chindaprasirt, P., Hatanaka, S., Mishima, N., Yuasa, Y., & Chareerat, T. (2009). Effects of binder strength and aggregate size on the compressive strength and void ratio of porous concrete. International journal of minerals, metallurgy and materials, 16(6), 714-719.

David K. Hein, P. E. (2013). Permeable Pavement Design And Construction.

Dept of Civil (Structural) Engineering, D. S. (2017). Study on Compressive Strength Of Pervious Concrete For Utilisation As Pavement.

Ding, K., & Zeng, C. (2025). Study on the compressive strength, pore structure characteristics, and fractal dimension of the ecological porous concrete specimens based on ordinary Portland cement. Construction and Building Materials, 483, 141795.

Ekolu, S., Ahmed, A., Quainoo, H., Konzapi, A., Thaimo, F., Solomon, F., Naghizadeh, A., Tyatya, X., & Gubeka, V. (2025). Strength and pore-related effects of crumb rubber as aggregate in roller compacted concrete for pavements. International Journal of Pavement Research and Technology. Advance online publication. https://doi.org/10.1007/s42947-025-00550-3

Elizondo-Martínez, E. J., Andres-Valeri, V. C., Jato-Espino, D., & Rodriguez-Hernandez, J. (2020). Review of porous concrete as multifunctional and sustainable pavement. Journal of Building Engineering, 27, 100967.

Hui, S., Fan, S., Wan, K., Yao, J., Yin, W., & Lee, Y. (2025). Balancing mechanical and permeability properties of pervious concrete through inter-aggregate pore structure optimization. Journal of Building Engineering, 106, 112537. https://doi.org/10.1016/j.jobe.2025.112537

Jaya, R. P. (2020). Porous concrete pavement containing nanosilica from black rice husk ash. In New Materials in Civil Engineering (pp. 493-527). Butterworth-Heinemann.

Katakam, R., Gobinath, R., & Shyamala, G. (2025). Research trend and knowledge gap analysis on fracture energy based concrete analysis and design. Journal of Infrastructure Preservation and Resilience, 6, 18. https://doi.org/10.1186/s43065-025-00129-z

Lamichhane, R., Motra, G. B., Khadka, T. B., Zhang, Y. X., Pathak, P., & Pandit, S. (2024). Impact of water level variation on mechanical properties of porous concrete. Sustainability, 16(9), 3546.

Lian, C., Zhuge, Y., & Beecham, S. (2011). The relationship between porosity and strength for porous concrete. Construction and building materials, 25(11), 4294-4298.

Lin, W., Park, D. G., Ryu, S. W., Lee, B. T., & Cho, Y. H. (2016). Development of permeability test method for porous concrete block pavement materials considering clogging. Construction and Building Materials, 118, 20-26.

Lv, Y., Chen, Y., Dai, W., Yang, H., Jiang, L., Li, K., & Jin, W. (2024). Preparation and properties of porous concrete based on geopolymer of red mud and yellow river sediment. Materials, 17(4), 923.

Moretti, L., Di Mascio, P., & Fusco, C. (2019). Porous concrete for pedestrian pavements. Water, 11(10), 2105.

Muda, M. M., Legese, A. M., Urgessa, G., & Boja, T. (2023). Strength, porosity and permeability properties of porous concrete made from recycled concrete aggregates. Construction Materials, 3(1), 81-92.

Nataraja, M. C., Srinivasamurthy, L., Das, V. R., & Vineeth, L. (2023). Effect of aggregate gradation on the mechanical strengths and permeability properties of porous concrete. Journal of Engineering and Applied Science, 70(1), 153. https://doi.org/10.1186/s44147-023-00325-2

Onstenk, E., Aguado, A., Eickshen, E., & Josa, A. (1993). Laboratory study of porous concrete for its use as top-layer of concrete pavements. In Proceedings of the International Conference on Concrete Pavements.

Park, S. B., & Tia, M. (2004). An experimental study on the water-purification properties of porous concrete. Cement and concrete research, 34(2), 177-184.

Ramadhansyah, P. J., Mohd Ibrahim, M. Y., Hainin, M. R., & Wan Ibrahim, M. H. (2014). A review of porous concrete pavement: applications and engineering properties. Applied mechanics and materials, 554, 37-41.

Reyad, M., ElTair, A. M., El-Nemr, A., & Jato-Espino, D. (2024). Mechanical and permeability behavior of porous concrete when using different aggregate sizes and adding polypropylene fiber. Journal of Materials in Civil Engineering, 36(6), 04024132.

Sai Sindhu K, S. B. (2015). Study and Comparision of Mechanical Properties, Durability and Permeability of M15, M20, M25 Grades of Pervious Concrete with Conventional Concrete. GIST RESEARCHER In-house Journal of Science and Technology.

Shanthi Vengadeshwari, R., Ujwal, M., Shiva Kumar, G., Mahesh, R., Sanjay, N., Rajiv, K. N., & Pandit, P. (2025). SHAP-based prediction and optimization of compressive strength in M30 concrete with dry sewage sludge as fine aggregate replacement. Discover Materials, 5, 183. https://doi.org/10.1007/s43939-025-00383-8

Tamai, H. (2015). Enhancing the performance of porous concrete by utilizing the pumice aggregate. Procedia Engineering, 125, 732-738.

Ukpata, J. O., Ewa, D. E., Success, N. G., Alaneme, G. U., Otu, O. N., & Olaiya, B. C. (2024). Effects of aggregate sizes on the performance of laterized concrete. Scientific Reports, 14, 448. https://doi.org/10.1038/s41598-023-50998-1

Zhu, H., Ma, Y., Zhang, D., Mao, M., & Li, J. (2025). Development of sustainable pervious concrete: Effects of coal gangue and GGBS on strength, frost resistance, and carbon efficiency. Low-carbon Materials and Green Construction, 3(1), 25. https://doi.org/10.1007/s44242-025-00082-w