International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: X Month of publication: October 2025

DOI: https://doi.org/10.22214/ijraset.2025.74562

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue X Oct 2025- Available at www.ijraset.com
Third International Conference on Construction Materials and Structures (2025)

Third International Conference on Construction Materials and Structures (2025)
"Synergy of Materials and Structures (SMS)"

Sustainable Porous Concrete Solutions for Groundwater Recharge and Stormwater Management

Niharika Patel[1], V. Madhava Rao[2], Prakash Chandra Swain[3], Mukesh Kumar[4]
[1]Ph.D. Candidate, [2]Professor, [4]PG Scholar, GIET Univeristy, Department of Civil Engineering, Gunupur, Odisha, India
[3]Professor, VSSUT Burla, Sambalpur, Odisha, India

Abstract: The rapid developments in the infrastructure and increasing pace of urbanization in cities, a significant portion of land is now covered with impermeable surfaces such as conventional concrete and bituminous pavements. These surfaces hinder natural rainwater infiltration, leading to increased surface runoff, urban flooding, and a decline in groundwater recharge. To address these challenges, this study explores the development of permeable (porous) concrete as a sustainable solution for effective stormwater management and enhanced groundwater replenishment. The proposed concrete mix eliminates fine aggregates to create interconnected voids, allowing water to percolate through the pavement and into the ground. In addition, the research aims to reduce the dependence on natural coarse aggregates by partially substituting cement with silica fume. Mix designs with silica fume replacement levels of 0%, 2.5%, and 5% were examined. Key parameters investigated are cement setting time, workability, compressive strength, split tensile strength, porosity, and permeability to evaluate its performance. Results show that porous concrete incorporating silica fume is technically viable and environmentally beneficial. While an increase in compressive strength and significant permeability was observed with addition of higher silica fume content and these traits are favorable for applications aimed at stormwater infiltration and groundwater recharge. This ecofriendly concrete is well-suited for low-traffic urban applications such as permeable pavements, pedestrian zones, and parking lots, where managing surface runoff and improving groundwater sustainability are critical. The study presents the environmental benefits of restoring natural water cycles in urban environments.

Keywords: Ground water recharge, permeability, porosity, compressive strength, porous concrete.

I. INTRODUCTION

As urban areas continue to grow, the need for pavement increases significantly, with paved surfaces making up around 30–45% of the built environment [1,2]. However, traditional impervious pavements contribute to problems such as waterlogging, flooding, and water pollution during heavy rainfall. In addition, these surfaces trap large amounts of solar energy and release excessive heat into the atmosphere owing to their high thermal inertia, which hampers natural evaporation processes and fosters the development of urban heat [3,4]. To mitigate these environmental challenges, there is a pressing need for sustainable practices and investments in pavement infrastructure. One promising solution is porous concrete — a type of pavement with a porous structure that enables water to pass through, supporting better stormwater management and reducing heat accumulation.

According to ACI 522R-2010 (American Concrete Institute, 2010), pervious concrete typically exhibits a compressive strength ranging from 2.8 MPa to 28 MPa, with water permeability between 0.135 and 1.21 cm/s (equivalent to 81–730 L/min/m²) [5]. Its pore sizes generally fall within the range of 0.15 to 8 mm, and it features a porosity of approximately 15% to 35% [6]. The density of pervious concrete usually lies between 1820 kg/m³ and 2100 kg/m³ [9]. Due to its eco-friendly nature and wide array of applications—including parking lots, subsurface drainage layers, greenhouse floors, road base layers, tennis courts, zoo enclosures, animal barns, and pool decks—pervious concrete is gaining significant attention [7]. In addition to its functional uses, it contributes to noise reduction, stormwater purification, and protection of urban vegetation [8]. Research indicates that Portland cement-based pervious concrete has the potential to remove heavy metals such as Zn, Cu, and Pb from water, primarily due to the strong binding capability of the calcium silicate hydrate (C–S–H) gel formed during cement hydration [9,10].

Nevertheless, the environmental impact of cement production remains a critical concern, primarily due to its high consumption of natural resources and substantial carbon dioxide emissions [11]. To mitigate these effects while improving the strength and durability of pervious concrete, researchers have explored the use of chemical and mineral admixtures.

Additives such as ground granulated blast furnace slag (GGBS), fly ash (FA), rice husk ash (RHA), and silica fume (SF) have been employed to enhance microstructural characteristics and reduce dependence on virgin cement materials [12]. These mineral components function as micro-fillers, improving the overall compactness and density of the concrete matrix [13].

Moreover, the partial replacement of cement with fly ash and silica fume has shown positive effects on both the workability and mechanical properties of fresh concrete. For example, a mixture incorporating 24% fly ash and 1.9% nano-silica achieved a compressive strength of 17.3 MPa with a permeability of 8.8 mm/s [14]. Another study reported a 7-day compressive strength of 5.0 MPa and a permeability of 4.3 mm/s using a blend of 60% fly ash and 0.04% nano-silica [15]. Similarly, Perez's research demonstrated that incorporating 35% fly ash and 6% nano-Fe_3O_4 resulted in a compressive strength of 22.8 MPa and a permeability of 5.6 mm/s after 28 days [16].

Recognizing the critical role of pervious concrete in addressing urban challenges such as waterlogging and flooding, further research into its structural and functional performance is essential. Despite extensive studies, the low compressive strength of pervious concrete—due to its high porosity and weak interconnects within the microstructure—remains a persistent limitation. This study aims to address this issue by focusing on the development of pervious concrete with enhanced compressive strength. The research investigates the effects of fly ash and silica fume as partial cement replacements on the mechanical and durability characteristics of pervious concrete. Specimens are tested after 7, 28, and 56 days of curing to evaluate the influence of curing duration on strength development and overall performance.

II. EXPERIMENTAL PROGRAM

A. Materials

In this study, 53-grade Ordinary Portland Cement (OPC) was sourced from a local supplier. Experimental tests revealed a cement fineness of 231 m^2/kg and a specific gravity of 3.14. Silica fume, obtained as a byproduct from the production of elemental silicon using electric arc furnaces, was also procured locally. It consisted of spherical, off-white particles with a specific gravity of 2.3, a mean particle size between 0.1 and 0.3 µm, and a very high fineness of 20,000 m^2/kg. Additionally, Class F (low calcium) Flyash is is also used as a partial replacement of cement having particle size ranging between 10 and 100 µm. Coarse aggregate of size ranging between 10 to 12.5 mm, were used in the current study. Normal tap water is used for concrete mix and Conplast SP 430 is used as admixture. The chemical composition of OPC, flyash (FA) and silica fume (SF) as shown in Table 1. The mix design is prepared following the guidelines mentioned in ACI 522R-10 which is shown in Table 2.

Table 1 Chemical composition of OPC, FA and SF

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O_3	K_2O	MgO
OPC	21.4	5.8	3.56	62.5	0.49	0.66	1.79
Silica fume	93.5	1.15	0.78	0.35	0.46	0.85	1.65
Flyash	56.8	18.7	10.6	3.5	0.26	-	1.89

Table 2 Mix proportions of various mixes

Composition	Cement (kg/m^3)	Fresh Water (kg/m^3)	SF (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	SP (kg/m^3)	Curing condition
OPC100%	376	190	--	--		2.28	Freshwater
OPC75%+FA20% +SF5%	282	190	19	75	1260	2.28	Freshwater
OPC70%+FA20% +SF10%	265	190	38	75	1260	2.28	Freshwater
OPC65%+FA20% +SF15%	244	190	57	75	1260	2.28	Freshwater
OPC60%+FA20% +SF20%	226	190	75	75	1260	2.28	Freshwater

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue X Oct 2025- Available at www.ijraset.com
Third International Conference on Construction Materials and Structures (2025)

B. Test Methods

All the specimens were cured and tested after a curing duration of 7, 28 and 56 days. The test methods to evaluate the mechanical and permeability characteristics of concrete are mentioned in Table 3.

Table 3 Details of specimens and its test methods

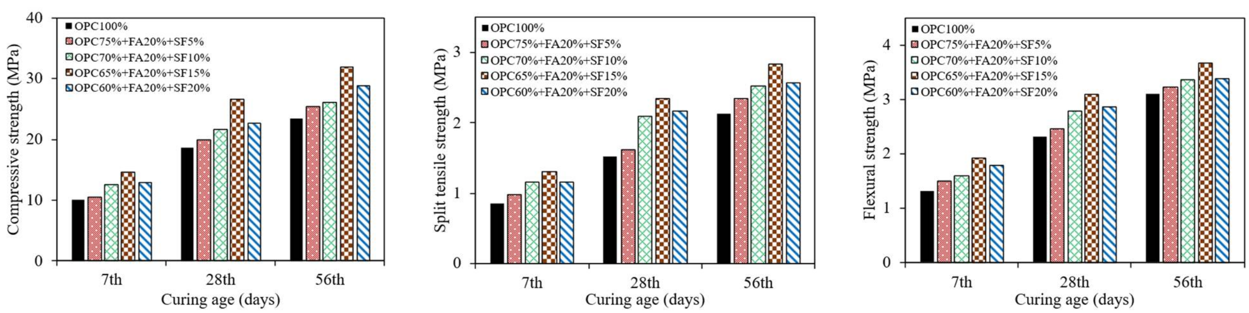
Property	Test standard	Specimen details	No. of specimens
CS	IS 516	Cubes (100×100×100 mm)	3
STS	ASTM C 496	Cylinders (100×200 mm)	3
FS	ASTM C932	Beams (100×100×500 mm)	3
Porosity	ASTM C 1688	Cylinders (100×200 mm)	3
Permeability	ASTM C1701M	Cylinders (100×200 mm)	3

III. RESULTS AND DISCUSSIONS

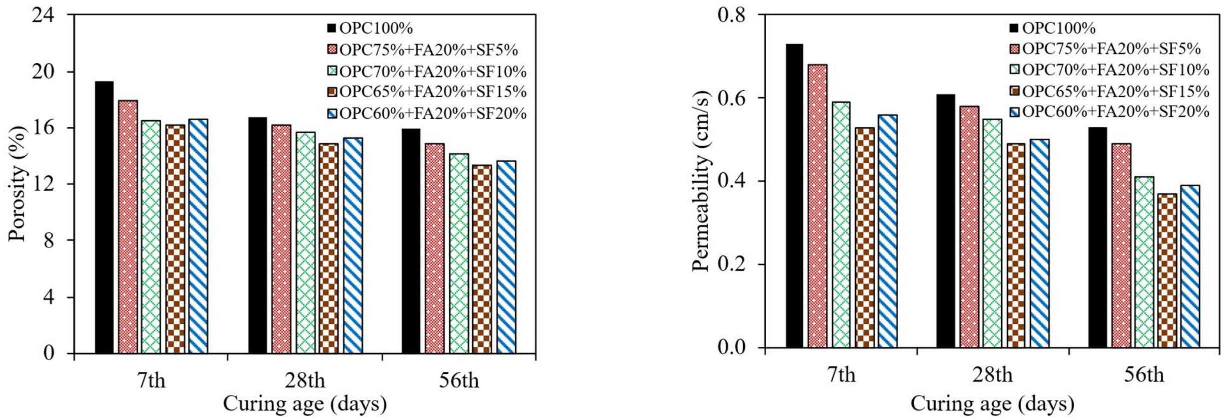
Figure 1 illustrates the mechanical and permeability characteristics of all the mixes in details. The experimental results reveal that the permeability of all concrete mixes decreases consistently with curing age (7, 28, and 56 days), with a notable reduction as the proportion of supplementary cementitious materials (fly ash and silica fume) increases. It is seen that mix OPC65%+FA20%+SF15% exhibited the least permeability of 0.53, 0.49 and 0.37 cm/s which 27%, 20% and 30% lower than control mic OPC100% at 7th, 28th and 56th day respectively. Similarly, porosity follows the same trend, decreasing with both curing time and higher FA and SF content, indicating a denser microstructure due to improved particle packing and ongoing pozzolanic reactions. OPC65%+FA20%+SF15% mix showed the least porosity compared to control mix with a reduction by 15%, 11% and 16.5% at 7th, 28th and 56th day respectively.

Flexural strength demonstrates a steady increase over time, with mixes incorporating higher percentages of FA and SF achieving comparable or superior strength to the control OPC100% mix by 56 days, highlighting the beneficial effects of the pozzolanic reaction and the high reactivity of silica fume. Split tensile strength also shows progressive improvement with curing, with FA and SF mixes surpassing or matching OPC100% at 56 days, attributed to enhanced matrix densification and better internal bonding. Compressive strength exhibits a significant rise with age, with high FA and SF content leading to superior performance over OPC100% at both 28 and 56 days, confirming the long-term strength advantages of using these supplementary materials. Specifically, it is to be noted that the mix OPC65%+FA20%+SF15% has emerged as an optimum mix exhibiting excellent mechanical and permeability characteristics.

This mix attained the highest compressive strength with an increment of 44%, 43% and 34%, highest tensile strength by 54%, 53% and 34% and peak flexural strength by 44%, 345 and 19% over control mix at curing period of 7, 28 and 56 days. Overall, the addition of FA and SF substantially improves the durability and mechanical properties of concrete, making it highly suitable for high-performance construction applications.



(a) (b) (c)



(d) (e)

Figure 1 (a) compressive strength, (b) Split tensile strength, (c) Flexural strength, (d) Porosity (%), (e) Permeability (cm/s) of various mixes

IV. CONCLUSIONS

The present study focuses on the development of pervious concrete, with particular emphasis on compressive strength as a key performance indicator. The effects of incorporating fly ash and silica fume as partial replacements for cement on the mechanical properties of pervious concrete are thoroughly investigated. Concrete specimens were prepared using varying proportions of fly ash and silica fume, and their mechanical and durability properties were evaluated after curing periods of 7, 28, and 56 days. Additionally, the study examines the influence of curing duration on the strength development of the pervious concrete mixes. The conclusions of the above experimental investigations is as follows.

1) Permeability of all concrete mixes decreased consistently with increasing curing age (7, 28, and 56 days), with greater reductions observed as the proportion of fly ash (FA) and silica fume (SF) increased.
2) Porosity showed a similar declining trend with curing time and higher FA and SF content, indicating the development of a denser microstructure due to enhanced particle packing and pozzolanic reactions.
3) Compressive strength, split tensile strength and flexural strength steadily improved with curing age, with mixes containing higher FA and SF percentages achieving higher strength than that of the control OPC100% mix by 56 days, attributed to improved matrix densification.
4) Overall, OPC65% + FA20% + SF15% mix emerged as the optimum mix with highest compressive strength increases of 44%, 43%, and 34%, highest tensile strength increases of 54%, 53%, and 34% and highest flexural strength increases of 44%, 34%, and 19% at 7, 28, and 56 days over control mix OPC100%.
5) Addition of FA and SF substantially improves the durability and mechanical properties of pervious concrete. The optimized mix is highly suitable for high-performance pavement constructions.

REFERENCES

[1] K. Jessup, S.S. Parker, J.M. Randall, B.S. Cohen, R. Roderick-Jones, S. Ganguly, J. Sourial, Planting Stormwater Solutions: a methodology for siting nature-based solutions for pollution capture, habitat enhancement, and multiple health benefits, Urban For. Urban Green. 64 (2021), 127300, https://doi.org/10.1016/j.ufug.2021.127300.

[2] E.O. Nnadi, A.P. Newman, S.J. Coupe, F.U. Mbanaso, Stormwater harvesting for irrigation purposes: an investigation of chemical quality of water recycled in pervious pavement system, J. Environ. Manag. 147 (2015) 246–256, https://doi.org/10.1016/j.jenvman.2014.08.020.

[3] J.H. Park, Y.U. Kim, J. Jeon, S. Wi, S.J. Chang, S. Kim, Effect of eco-friendly pervious concrete with amorphous metallic fiber on evaporative cooling performance, J. Environ. Manag. 297 (2021), 113269, https://doi.org/10.1016/j.jenvman.2021.113269.

[4] J.S. Tyner, W.C. Wright, P.A. Dobbs, Increasing exfiltration from pervious concrete and temperature monitoring, J. Environ. Manag. 90 (2009) 2636–2641, https://doi.org/10.1016/j.jenvman.2009.02.007.

[5] P. Shen, J.X. Lu, H. Zheng, S. Liu, C. Sun Poon, Conceptual design and performance evaluation of high strength pervious concrete, Construct. Build. Mater. 269 (2021), 121342, https://doi.org/10.1016/j.conbuildmat.2020.121342.

[6] Z. Zhang, Y. Zhang, C. Yan, Y. Liu, Influence of crushing index on properties of recycled aggregates pervious concrete, Construct. Build. Mater. 135 (2017) 112–118, https://doi.org/10.1016/j.conbuildmat.2016.12.203.

[7] J.X. Lu, X. Yan, P. He, C.S. Poon, Sustainable design of pervious concrete using waste glass and recycled concrete aggregate, J. Clean. Prod. 234 (2019) 1102–1112, https://doi.org/10.1016/j.jclepro.2019.06.260.

[8] S.P. Yap, P.Z.C. Chen, Y. Goh, H.A. Ibrahim, K.H. Mo, C.W. Yuen, Characterization of pervious concrete with blended natural aggregate and recycled concrete aggregates, J. Clean. Prod. 181 (2018) 155–165, https://doi.org/10.1016/j.jclepro.2018.01.205.

[9] M. Nazeer, K. Kapoor, S.P. Singh, Pervious concrete: State-of-the-art Rev. 7 (2020) 417–437.

[10] C. Ngohpok, V. Sata, T. Satiennam, P. Klungboonkrong, P. Chindaprasirt, Mechanical properties, thermal conductivity, and sound absorption of pervious concrete containing recycled concrete and bottom ash aggregates, KSCE J. Civ. Eng. 22 (2018) 1369–1376, https://doi.org/10.1007/s12205-017-0144-6.

[11] S. Afridi, M.A. Sikandar, M. Waseem, H. Nasir, A. Naseer, Chemical durability of superabsorbent polymer (SAP) based geopolymer mortars (GPMs), Construct. Build. Mater. 217 (2019) 530–542, https://doi.org/10.1016/j.conbuildmat.2019.05.101.

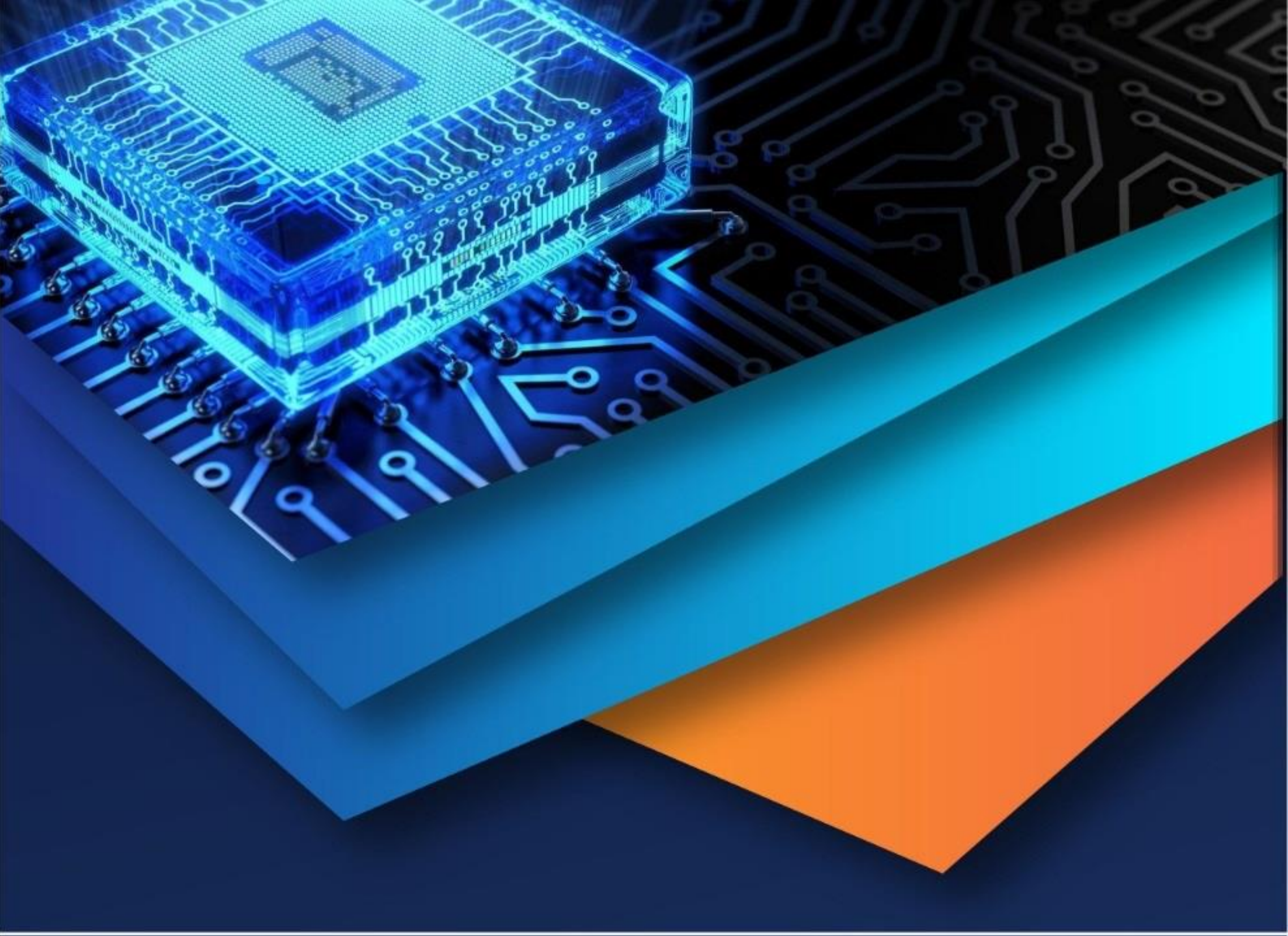
[12] R. Liu, Y. Chi, S. Chen, Q. Jiang, X. Meng, K. Wu, S. Li, Influence of pore structure characteristics on the mechanical and durability behavior of pervious concrete material based on image analysis, Int. J. Concr. Struct. Mater. 14 (2020) 1–16, https://doi.org/10.1186/s40069-020-00404-1.

[13] Z. Proˇsek, V. Neˇzerka, R. Hlůˇzek, J. Trejbal, P. Tes´arek, G. Karra'a, Role of lime, fly ash, and slag in cement pastes containing recycled concrete fines, Construct. Build. Mater. 201 (2019) 702–714, https://doi.org/10.1016/j.conbuildmat.2018.12.227.

[14] V. L´opez-Carrasquillo, S. Hwang, Comparative assessment of pervious concrete mixtures containing fly ash and nanomaterials for compressive strength, physical durability, permeability, water quality performance and production cost, Construct. Build. Mater. 139 (2017) 148–158, https://doi.org/10.1016/j.conbuildmat.2017.02.052.

[15] M. Jo, L. Soto, M. Arocho, J. St John, S. Hwang, Optimum mix design of fly ash geopolymer paste and its use in pervious concrete for removal of fecal coliforms and phosphorus in water, Construct. Build. Mater. 93 (2015) 1097–1104, https://doi.org/10.1016/j.conbuildmat.2015.05.034.

[16] L. Soto-P´erez, S. Hwang, Mix design and pollution control potential of pervious concrete with non-compliant waste fly ash, J. Environ. Manag. 176 (2016) 112–118, https://doi.org/10.1016/j.jenvman.2016.03.014.



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY